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Joint Battery Industry Sector Study

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This study, sponsored by the North American Technology and Industrial Base Organization (NATIBO), assesses the long term health of the North American military battery production base. This horizontal assessment identifies batteries that have commercial applications, dual use batteries meeting DoD needs, and batteries that meet unique military requirements. It also identifies battery chemistries where the capability to manufacture that particular line may disappear and discusses the impact of this loss and the potential of new or next generation battery chemistries to fill the void. The study identifies current problems, the outlook for the industry, areas of compatibility, and areas of potential joint Service and Canadian cooperation. From this, the study provides recommendations for managing batteries within the military and overcoming identified problems. The report outlines concrete initiatives for improving the battery industry sector, employing dual use batteries to the maximum extent, and enhancing joint activity.

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Joint Battery Industry Sector Study

Prepared for:

The North American Defense

Industrial

Base Organization

(NADIBO)

Prepared by: *BDM Federal, Inc.* *August 31, 1994*

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FOREWORD

This report addresses the collection and analysis of technical, market, and policy information related to the North American battery industry sector. The report includes information gathered from a wide variety of sources.

The report was prepared by BDM Federal, Inc. (BDM), 1501 BDM Way, McLean, Virginia 22102 for the U.S. Army Industrial Engineering Activity (IEA); the Productivity Branch, Industrial Base Analysis Division, Manufacturing Technology Directorate, Wright Laboratory, Wright Patterson Air Force Base, U.S. Air Force; and the Directorate of North American Material Cooperation of the Canadian Department of National Defence on behalf of the North American Defense Industrial Base Organization (NADIBO) under contract number DAAA08-91-D-0008. Ed Dorchak managed the Battery Sector Study. Donald Higgins, Jr. was the technical lead. Principal authors were Mel Hafer, Ellen Solos, and Stephen Milley.

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EXECUTIVE SUMMARY

Introduction

This study, sponsored by the North American Defense Industrial Base Organization (NADIBO), assesses the long term health of the North American military battery production base. The objective of the report is to discuss the following areas:

- Batteries and battery chemistries that military systems use today
- U.S. and Canadian production capabilities relative to these chemistries
- Battery technology trends and research and development programs regarding current and future military battery systems
- The current and projected business climate for producers of military batteries
- Marketplace issues and concerns.

This horizontal assessment identifies batteries that have commercial applications, dual use batteries meeting DoD needs, and batteries that meet unique military requirements. It also identifies battery chemistries where the capability to manufacture that particular line may disappear and discusses the impact of this loss and the potential of new or next generation battery chemistries to fill the void.

The study identifies current problems, the outlook for the industry, areas of compatibility, and areas of potential joint Service and Canadian cooperation. From this, the study provides recommendations for managing batteries within the military and overcoming identified problems. The report outlines concrete initiatives for improving the battery industry sector, employing dual use batteries to the maximum extent, and enhancing joint activity.

In the course of this study, government and industry representatives were interviewed and site visits to battery producers and research laboratories were conducted. An extensive database of battery information was compiled.

The following sections provide a snapshot view of the battery industrial base by chemistry. Following the discussion of the chemistry families is a discussion of general management issues and concerns of the battery industrial base as a whole. This includes recommendations to handle these issues.

Thermal Batteries

The term thermal battery does not refer to any one type of battery chemistry but to a group of electrochemical systems using different chemistries. The most common configurations are lithium based systems. These types of batteries are for one time use and provide power for mines, missiles, guided artillery, fuses, countermeasure devices, and guidance systems. Activated pyrotechnically, the electrochemical reaction cannot be stopped and has a duration of a few seconds to a few hours. Thermal batteries are used exclusively by the military, though R&D is underway to address commercial applications.

Eagle-Picher's Joplin, Missouri facility is the only remaining North American producer of thermal batteries. SAFT America in Cockeysville, Maryland ceased thermal battery production in December of 1993 and became a R&D facility. Two other companies, Martin Marietta and Westinghouse, recently have shown thermal battery production capabilities for R&D and prototype batteries.

Thermal battery demands are significantly lower than in the past due to cancellation of developmental weapons programs and other defense cutbacks with no foreseeable growth in the near future. However, thermal batteries are being assessed for additional military applications in sonobuoys and BAT smart missiles and for a commercial application as emergency power on More Electric Aircraft. (MEA) A new series of sonobuoys may replace lithium sulfur dioxide batteries with a thermal battery system. This application is in the development phase but if successful, could significantly increase military demand for thermal batteries. The development of the MEA will establish a commercial demand for thermal batteries if the emergency backup systems using these batteries prove successful.

The thermal battery base has a projected business climate that is stable and flat. One solid producer is currently supplying thermal batteries, and other potential producers are considering entry into the market.

Lithium Batteries

Lithium batteries are used primarily in military applications, though there is some spin-off into the commercial market. Lithium primary batteries offer performance advantages well above the capabilities of conventional aqueous electrolyte battery systems. They have the highest

gravimetric energy (watt hours/kilogram), highest volumetric energy (watt hours/liter), and one of the best storage lives of any electrochemical battery system.

The lithium chemistries used by the military include primary lithium sulfur dioxide, lithium thionyl chloride, and lithium manganese dioxide. At present, the most widely used of these chemistries is lithium sulfur dioxide. Defense applications include global positioning systems, silo batteries, SINCGARS radios, sonobuoys, and torpedoes. The commercial market uses lithium batteries in a small number of applications. Commercial applications of primary lithium thionyl chloride batteries include animal tracking devices, oil drilling electronics, timing devices, and life support systems. Primary lithium manganese dioxide batteries are used commercially in watches, calculators, laptop computers, cellular telephones, and cameras, and lithium sulfur dioxide batteries in medical devices, animal tracking devices, and lighting on mining helmets.

There are four major North American lithium battery producers - Ballard Battery Systems, Battery Engineering Inc. (BEI), Power Conversion Inc., and SAFT America Inc. (Valdese). A fifth company, Yardney Technical Products, is a potential supplier of lithium systems to the military but, to date, has not produced any batteries. The present market for lithium batteries represents a small fraction of the overall battery market. The lithium marketplace has been driven by military sales, with commercial sales accounting for only a small portion of the overall demand.

Due to the large number of lithium sulfur dioxide batteries procured by CECOM during Operation Desert Storm and the completion of existing contracts, sufficient supplies exist to preclude any further major procurements until the 1997/1998 time frame. During this time period, the military is examining the cost effectiveness of alternative lithium battery systems. In particular, CECOM is examining the lithium manganese dioxide (pouch) battery as a potential candidate to replace the lithium sulfur dioxide battery. CECOM is concerned about the tradeoffs between the current performance level of the lithium sulfur dioxide battery versus new lithium batteries and the costs associated with these different systems. If the next generation of lithium batteries does not prove as cost effective as the current lithium sulfur dioxide system, this concern is that lithium sulfur dioxide battery producers may not be available when CECOM needs to procure more batteries. CECOM is postured to accept this risk and believe if they continue to procure the lithium sulfur dioxide battery, a supplier will either still have the production capability or the ability to resurrect it.

A large part of the military's primary battery budget is for lithium batteries. The major focus of military R&D activities is toward improved safety and performance of existing primary

systems and development of secondary lithium systems. The secondary systems being addressed are lithium ion and lithium polymer batteries. Sony has recently introduced a lithium ion battery in the commercial market for its camcorders.

Of the major lithium battery manufacturers, only BEI has an established commercial market, primarily for the oil drilling industry, and does not rely on government sales. The other producers rely heavily on government sales for their survival. The possible transition away from the lithium sulfur dioxide chemistry, previously the military's mainstay chemistry, has left the lithium producers concerned about their future prospects. Product diversification based on increased commercial demand is essential for developing a healthy lithium battery industrial base. The military demand in support of present and future systems will be limited. Manufacturers are investigating commercial marketplace applications for their products. Much attention is being centered on development of the lithium ion and lithium polymer technologies, which lend themselves to both commercial and military uses. Most lithium battery manufacturers do not have dedicated lines to produce military batteries and are postured to treat their commercial and military customers equally. The companies will add additional shifts to meet extra military demand, but will not make capital investments to support military production alone. In a crisis situation, they will be well positioned to use their full capacity to support military production.

There are several Technology Reinvestment Program contracts that recently have been awarded, and many are under negotiation, to assist military based lithium battery producers to make the transition to commercial products. This will help provide financial stability and at the same time maintain military battery production capabilities.

The demand for lithium batteries is projected to increase for both primary and secondary (rechargeable) batteries. This growth is expected largely as a result of increased demand and sales of portable electronic devices using lithium ion and lithium polymer batteries. Military demand may no longer dictate the climate of the lithium marketplace in the future.

Mercury Batteries

Mercury batteries are not a high demand battery chemistry. The market is almost totally driven by the military. The military uses this chemistry in legacy systems, namely mines, munitions, and communications devices dating from the 1960s and early 1970s, naval mines, and surveillance systems. Commercial applications are limited to portable electronics and portable medical devices.

The DoD is transitioning away from mercury batteries and into other chemistries, primarily due to environmental concerns. Due to safety issues involving mercury, 13 states have banned the commercial sale of mercury batteries, and it is likely that more will follow.

Alexander Batteries is the only North American producer of mercury cells and only world producer of cylindrical mercury cells. As DoD replaces these legacy systems and phases out mercury batteries, Alexander Batteries will probably discontinue mercury battery manufacturing. The commercial market will not provide the company with enough business to sustain production.

Silver Zinc/Silver Cadmium Batteries

The silver battery market is small and serves niche markets. One of the main reasons that this market has not expanded is the high cost of the battery. The most widely used silver batteries are silver zinc and silver cadmium; the silver zinc system exists in primary, primary reserve, and secondary configurations. Defense uses of the silver cadmium battery are for powering torpedoes and satellites. Commercial silver cadmium battery applications are limited to portable power tools. Military applications of secondary silver zinc systems are for guidance and telemetry for missiles and torpedoes and propulsion for underwater vehicles and torpedoes. NASA uses this chemistry in all their space missions. Commercial applications of secondary silver zinc batteries are electronic news gathering equipment and television cameras. The major commercial silver battery is the silver zinc primary chemistry, which is used in electronic devices such as calculators and wristwatches. The silver zinc batteries used by the military are quite different from the small, single primary cell batteries used in commercial electronic devices.

Yardney Technical Products, Inc. and BST Systems are the North American producers of silver cadmium batteries. For military applications of primary and secondary silver zinc batteries, there are four main North American suppliers - Yardney, BST, Whittaker Power Storage Systems, and Eagle-Picher Industries, Inc. (Joplin, Missouri facility). For military applications of primary reserve silver zinc batteries, there are three main suppliers - Yardney, Whittaker, and Eagle-Picher. Commercial primary silver zinc cells are manufactured by Duracell, Eveready, and Rayovac.

Silver cadmium is an expensive battery chemistry with limited applications and an environmentally unfriendly component, cadmium. Environmental concerns over cadmium, decreasing defense dollars, and near term potential replacement chemistries will likely cause the military to discontinue use of silver cadmium batteries over time.

The commercial base for silver zinc batteries is quite distinct from the military, mainly due to the battery type used in each market. Commercial and military silver batteries cannot be manufactured on the same line and there appears no chance for dual use production in the near term.

Silver zinc battery usage within the military will grow in the near future with improved silver zinc batteries. Research is ongoing to improve the properties and lifecycle of silver zinc batteries.

The projected business climate overall for silver zinc batteries is stable with a slight downturn in demand. NASA and the Navy should continue to be a major customers of silver zinc batteries. The base is considered healthy, though the decrease in demand could result in the loss of one supplier. In particular, of the three primary reserve silver zinc suppliers of Navy batteries, only Eagle-Picher shows strong presence; Yardney's most recent production contract ended in FY93, and Whittaker's production does not have a strong foothold.

Lead Acid Batteries

Lead acid battery technology has been in use for over 100 years. Lead acid batteries are the most widely used secondary (rechargeable) batteries in the world. Applications span the range from small portable electronics to large military systems. The popularity of lead acid batteries is attributed to the maturity of the technology, the low maintenance (O&S) costs, the low cost of materials, the widespread recycling of lead, and a relatively wide temperature range for cycling and non-cycling applications.

The military uses lead acid batteries primarily for vehicle starting, lighting and ignition, aircraft engine starting, motive power on submarines, and standby power systems in missile silos. The commercial lead acid battery market is almost totally driven by automotive and standby power applications, although they are also used in portable computers and communications devices. The largest market for lead acid batteries is in the automotive aftermarket (replacement batteries). The commercial demand has kept the lead acid market stable and growing slowly.

Lead acid batteries are one of the most probable candidates for use in electric vehicles in the near term. Newer lead acid batteries, the valve-regulated, low maintenance types, are replacing many of the older lead acid batteries in many aviation systems.

Four major North American lead acid battery producers are Concorde Battery Corporation, C&D Charter Power Systems, GNB Battery Technologies, and Johnson Controls Battery Group. There are other lead acid battery suppliers to commercial markets, but this report only discusses these four suppliers and their presence in the military/government environment. Johnson Controls is the only producer of these that does not supply batteries directly to military organizations. The lead acid market is dominated by commercial demand. The only military application of lead acid batteries that has no commercial counterpart is submarine propulsion, due primarily to the large size of the battery system. Lead acid battery companies that supply the military have strong commercial markets, and the loss of military sales would not damage the market presence of these companies.

With an established commercial base and market, the lead acid battery industry is expected to continue strong growth. The base is considered healthy and the technology truly dual use, offering full convertibility of commercial and defense manufacturing lines.

Nickel Cadmium Batteries

Nickel cadmium is the most widely used nickel chemistry in the military. Nickel cadmium batteries have a rugged construction and proven reliability. Characteristics like high power capabilities, a wide operating temperature range, and long cycle life make them suitable for many applications. The military uses nickel cadmium batteries for aircraft and aerospace equipment. The commercial market for nickel cadmium batteries is driven primarily by portable electronics and commercial aviation sales. Military and commercial batteries are manufactured on the same production lines.

Presently, North America has three major military nickel cadmium battery suppliers, Eagle-Picher (Colorado Springs), Marathon Power Technologies, and SAFT America (Valdosta). These producers all serve a larger commercial market than their military market.

The replacement of vented nickel cadmium batteries with sealed nickel cadmium batteries in commercial and general aviation aircraft will increase sales in the near to mid term for the nickel cadmium market. The Air Force is working to retrofit vented nickel cadmium batteries with sealed nickel cadmium batteries in the B-52, F16, and E8 AWACS aircraft. The F18 will use sealed lead acid batteries.

As defense dollars and programs decrease and the life of nickel cadmium batteries is improved, there will be decreased demand in the long term for these batteries. These sealed nickel cadmium batteries are stored easily (in a discharged state), have a long shelf life, and a long service life. Therefore, the services will require fewer sealed nickel cadmium batteries due to these advances.

Though military demand will decrease, commercial demand will remain relatively stable. The projected business climate is good, with three healthy suppliers and full dual use capabilities.

Nickel metal hydride batteries are being studied as a potential replacement for some nickel cadmium batteries. Nickel metal hydride batteries have not yet reached maturity but are considered to offer increased performance and decreased manufacturing cost compared to nickel cadmium batteries. The absence of cadmium also is a significant environmental advantage. Primary use of these batteries currently is for powering personal notebook computers. These batteries are not yet available except in small sizes at high cost.

Magnesium Batteries

Magnesium manganese dioxide batteries are an old chemistry with limited applications and no strong foothold in either the military or commercial marketplace. The Navy uses magnesium batteries for mines and the Army uses them as a lower cost alternative to lithium batteries for portable electronics during training exercises. Commercially, these batteries are used for emergency locator beacon applications and other portable electronic applications. The commercial demand for these batteries dominates the market.

There are two North American suppliers of magnesium batteries to the military. ACR Electronics is the single manufacturer of magnesium batteries in support of the Navy's Captor mine. Rayovac sell its commercial line batteries to CECOM for the Army's portable electronics equipment.

Presently, the market for the magnesium batteries is stable. This chemistry will continue to be used in limited fashion and will eventually be replaced with new, longer lasting primary chemistries.

Figure EX-1 summarizes the battery marketplace by chemistry.

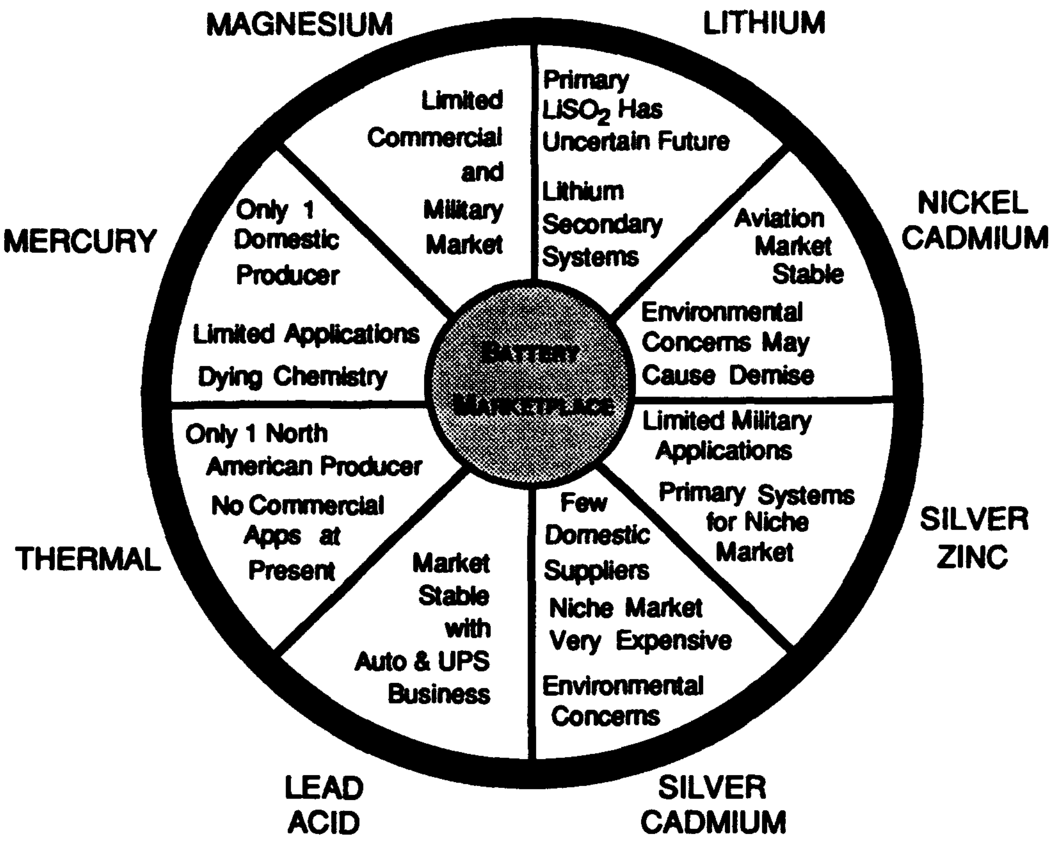

Figure EX-1. Battery Marketplace by Chemistry

Figure EX-2 summarizes the status of the North American military battery industry by chemistry including military and commercial demand, current and projected health of battery suppliers, current and projected health of battery chemistries, and dual use nature of the chemistries.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Thermal	medium military demand	one healthy supplier	healthy	stable and flat	N/A
	no commercial demand				
	potential for emergency power systems in commercial	others considering entry			
Lithium	military demand for lithium sulfur dioxide decreasing	five companies with poor to good health	diversification from military to commercial market is a concern due to rapid military decrease and slow commercial increase	need product diversification based on increased commercial demand	lithium sulfur dioxide likely to be replaced by lithium manganese dioixde
	increased military interest in other lithium chemistries				lithium thionyl chloride dual use today (bobbin config)
	small commercial demand	concern for 1995 to 1997 time frame	military transition to lithium manganese dioxide should support at least two suppliers		lithium ion dual use for future
	commercial demand for lithium ion and lithium polymer increasing		suppliers looking for commercial market to sustain business		
Mercury	military demand decreasing	presently stable	not required	market going away	N/A
	small, niche commercial demand	eventually supplier will disappear			
Silver	mostly military demand	four suppliers with fair to good health	healthy	stable but overall demand decreasing	N/A
	some commercial demand		silver cadmium going away	may lose one supplier	
Lead Acid	high commercial demand	four healthy suppliers	healthy	exellent and expanding	full conve[illegible]ability and dual use
	piggy-back military applications				
	new commercial applications for future				
Nickel Cadmium	high commercial demand	three healthy suppliers	healthy	excellent and expanding	full convertability and dual use
	piggy-back military applications				
Magnesium	small military demand	two healthy suppliers	healthy	stable and flat	Army uses dual use batteries
	small commercial demand				Navy does not use dual use batteries

Figure EX-2. Status of North American Military Battery Industry by Chemistry

Battery Industrial Base Management Conclusions

The design of military systems often does not consider power sources or battery systems early in the process. This leads to the specification of military-unique, system-unique battery sources that can be costly for manufacture and support. This design process and battery selection should be an integral part of the system design process enabling designers to capitalize on dual use chemistries, standardize the selection of batteries, and decrease the proliferation of military-unique, system-unique batteries.

The National/NATO Stock Number (NSN) assignment system is not efficient or well-maintained. Currently, the U.S. has an estimated 3,500 battery NSNs, and Canada has over 600. In addition identical batteries from the same suppliers often have different NSNs among military Services or between the U.S. and Canada. The process of cataloguing, tracking, and assigning NSNs needs serious attention to improve its effectiveness.

Related to the NSN issue is the lack of a complete, well-utilized, accurate database of batteries throughout the military. Such a tracking tool could drastically aid in reducing the proliferation of unique batteries, reducing the duplication of NSNs, and serving as a designers' tool for standardizing families of batteries for particular families of systems. Currently several databases include information like battery chemistry, configuration, power specifications, and physical specifications, but these databases are not fully populated, not completely accurate, and not fully utilized by the targeted audience.

The procurement processes and strategies of the U.S. military and Canadian DND can be more cost effective than they are today. There currently are no joint purchasing programs between the Services or with the DND. Each organization handles procurements individually with little or no coordination. In a number of instances, the same batteries are being procured from the same manufacturer. The Services and the DND can likely decrease unit costs by purchasing larger quantities in a joint procurement program.

The battery maintenance procedures within the military organizations could be updated, and training of personnel could reduce maintenance costs. Many battery chemistries require standard, periodic maintenance that perpetuate the life of the battery. If these maintenance procedures or time intervals are not followed, battery life decreases, resulting in unnecessary maintenance or

replacement costs. Several military organizations expressed concern that these procedures are not always accurate and that recommended time intervals for maintenance are not always followed.

The battery sector does not regard compliance with environmental regulations as a competitive concern. Battery manufacturers accept environmental safety procedures as standard operating practices. Some more environmentally unfriendly batteries are experiencing pressure to terminate their use, and some batteries, namely mercury and those including a cadmium component, will be phased out in the future.

Battery Industrial Base Management Short Term Recommendations

The U.S. and Canadian governments currently do not have a procurement program that encourages joint battery purchases among the U.S. Services or between the U.S. and Canadian military. Since this joint procurement process could decrease the unit cost of batteries, the two governments should institute such a procurement program.

Defense cutbacks have drastically decreased the production demand for many battery types, and not all suppliers are positioned to maintain manufacturing lines for stop-and-go production. The military organizations should attempt to spread the demand requirements over longer periods of time when it appears future demand will be reduced. This low rate production allows suppliers to maintain the particular manufacturing capability during periods when that particular production need is doubtful.

The lack of communication between military organizations and battery suppliers concerning battery procurement plans and requirements is a problem. The U.S. and Canadian governments should improve these communication efforts to allow suppliers to plan more effectively and maintain production stability. Advances in electronic commerce, such as the use of electronic bulletin boards, can facilitate communication of future battery procurements.

An effective way to reduce lifecycle costs of batteries is to reduce the costs of standard maintenance operations. Currently, the maintenance procedures for weapon systems' batteries are not completely up-to-date or accurate; the military Services and DND should update, improve, or renew these standard maintenance procedures and training procedures of the personnel responsible for preventative maintenance.

Battery Industrial Base Management Long Term Recommendations

Since the battery NSNs across the military services and the Canadian DND are not standardized and much duplication exists for similar battery configurations, the two governments should institute a thorough parsing of these NSNs and determine the corrections and streamlining that are required. During this process, the accurate, efficient NSN assignments should be collected into a joint database that includes categories of NSNs and information concerning the battery specifications.

Using the NSN database or a similar database as its basis, a designers' tool should be created that facilitates battery selection using parameters such as configuration, power specifications, physical specifications, manufacturers, contacts, and applications. This database will allow the targeted users - system designers, Project/Program Managers, and procurement personnel - to access a complete database of existing batteries in order to select a power source that will meet new system requirements.

A step beyond the designers' tool is the creation of families of batteries that are chemistries and configurations specific to particular application types. These families will help to control the proliferation of chemistries and configurations used on particular systems and will allow new batteries in the families to be designed with similar parameters and specifications. These families could be incorporated within the designers' tool described above.

Military specifications and standards that govern the design and manufacturing processes of different batteries are often out-of-date and not followed strictly. A joint revision of Mil-Specs and the relaxation of unnecessary, over-burdensome specifications will allow manufacturers to increase their dual use production capability and thus increase their stability.

Multiple-year contracting allows suppliers to maintain particular manufacturing capabilities with the assurance that future periods of production are likely. Since this type of working relationship would prove cost effective to both the military organizations and the suppliers, the military should attempt to create these multiple-year contracts wherever necessary to ensure the production base.

Finally, since the above recommendations cover a variety of issues and a variety of areas, the U.S. and Canadian governments should create a joint function to oversee the planning, implementation, and progress of the efforts made to improve the battery industrial base.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NORTH AMERICAN DEFENSE INDUSTRIAL BASE ORGANIZATION
JOINT BATTERY SECTOR STUDY

1.0 PURPOSE

The purpose of this study was to conduct an industrial base assessment of the North American battery industry sector and to recommend a cost effective strategy for meeting future military battery needs. This report addresses the ability of the sector to remain viable and advance in the current and projected economic environment. It also investigates how the different organizations involved in this study can work together to enhance the level of joint effort to sustain the health of the marketplace.

2.0 OBJECTIVES AND REPORT STRUCTURE

2.1 Objectives

This study assesses the long term health of the North American military battery production base. The objective of the report is to discuss the following issues:

- Batteries and battery chemistries that military systems use today;
- U.S. and Canadian production capabilities relative to these chemistries;
- Battery technology trends and research and development programs regarding current and future military battery systems;
- The current and projected business climate for producers of military batteries;
- Marketplace issues and concerns.

This horizontal assessment identifies batteries that have commercial applications, commercial batteries meeting DoD needs, and batteries that meet unique military requirements. It also identifies battery chemistries that may cease production and discusses the impact of this loss and the potential of new or next generation battery chemistries to fill the void.

The study identifies current problems, the outlook for the industry, areas of joint Service and Canadian cooperation, areas of compatibility, duplicative efforts, and potential bottlenecks. From this, the study provides recommendations for managing batteries within the military, investing in battery technology, and overcoming identified problems. The report outlines concrete

initiatives for improving the battery industry sector, employing commercial batteries to the maximum extent, and enhancing joint activity.

2.2 Report Structure

Section 3.0 of the report defines the scope of the study. Section 4.0 highlights the background of the formation of the NADIBO Joint Sector Study Working Group and the selection of batteries as the first study to be undertaken by this group. Section 5.0 then describes the methodology that was used to conduct the study.

Section 6.0 provides a technical description of the battery sector. It gives a generic definition of cell and battery, discusses the various components that make up a battery, breaks out the classification of batteries by primary (non-rechargeable) and secondary (rechargeable), and describes each battery family by chemistry. This section also explains the basics of how cell configurations are manufactured and repackaged and describes the battery chemistries and their respective properties.

Section 7.0 outlines current battery production across North American industry and describes the production and demand trends in the military and commercial battery arena. This includes a description of battery manufacturing companies across North America and their current and future business expectations. This section also describes production changes in which particular battery producers may be involved.

Section 8.0 addresses the research and development initiatives underway in the industrial battery marketplace. It discusses, by chemistry, trends or changeovers of certain technologies and chemistries and describes the latest research and development programs attempting to define the future battery marketplace.

Section 9.0 provides an assessment of the battery marketplace. It discusses the overall health of the North American battery arena and the individual health of each chemistry. This section cites single source battery dependencies and discusses viabilities and vulnerabilities of the battery marketplace as compared to expected future demands and trends.

Section 10.0 summarizes the information gathered in the previous sections and presents general conclusions about the different battery chemistries' health and market presence. It also provides, for each battery chemistry, recommendations to create a successful, long range, cost

effective strategy for meeting future military battery needs and enhancing joint activity. The strategy includes dual use considerations between military and commercial batteries and manufacturing facilities and battery chemistry changeovers into the next century.

3.0 SCOPE

This study entails the collection and analysis of technical, business, and policy information related to battery capabilities and trends within the U.S. and Canada. It provides a representative view of military battery chemistries and battery manufacturers.

The report presents battery manufacturers that produce military batteries or both military and commercial batteries, but it discusses the production scenarios of these companies as they affect the military battery industrial base. It does not address the commercial battery market except where military manufacturers also have commercial product lines. The study is not concerned with off-the-shelf batteries in the retail market such as alkalines, button cells for applications such as wristwatches and calculators, or other common commercial batteries.

The report covers seven battery chemistry groups: thermal, lithium, mercury, silver, lead acid, nickel cadmium, and magnesium.

4.0 BACKGROUND

The North American Defense Industrial Base Organization (NADIBO) is chartered to foster cooperative planning and defense industrial base program development between the U.S. and Canada. With this mission, the NADIBO has completed successfully several sector studies. In March, a group of technical representatives from the U.S. Military Services and their Canadian counterparts met to identify and prioritize cooperative sector study opportunities, culminating in the development of a list of sectors feasible for joint study. By examining together a sector of mutual interest, these organizations determined that they could cost effectively capture the critical industrial base information they need to conduct industrial base planning to meet current and future operation requirements. Through this initiative, common areas which could be assessed jointly were identified, avoiding a duplication of effort and capitalizing on scarce resources. Areas that were of joint interest to the group were batteries, thermo electric coolers, gallium arsenide, radar, and passive sensors. The battery sector was rated the highest priority since it is prevalent throughout all military systems and there is concern about the future ability of the industry to meet sudden increases in demands and/or to regenerate inventory.

The NADIBO battery sector study represents a unique initiative to involve all Services, the Defense Logistics Agency, and the Department of National Defence in a cooperative effort to investigate an industrial sector as it affects the U.S. and Canadian forces. The NADIBO Joint Battery Sector Study Working Group was established to conduct this effort.

This group consists of members from the Production Base Directorate of the Office of the Assistant Secretary of Defense; the U.S. Army Industrial Engineering Activity; the U.S. Army Missile Command; the U.S. Army Communications and Electronics Command; the Productivity Branch, Industrial Base Analysis Division, Manufacturing Technology Directorate, Wright Laboratory, Wright Patterson Air Force Base, U.S. Air Force; the NAVSEA Shipbuilding Support Office; the Naval Surface Warfare Center, Crane Division; the Naval Surface Warfare Center/Dahlgren Division; the Marine Corps; the Defense Logistics Agency; the Federal Emergency Management Agency; the Bureau of Mines of the U.S. Department of the Interior; and the Canadian Department of National Defence and the Chief Research and Development (CRAD). The study was officially kicked off in September of 1993.

5.0 METHODOLOGY

To conduct the battery industrial base study, a clear, concise, and well defined methodology was required to effectively survey the industry and develop an objective view of the entire sector, including military, commercial, foreign, political, and academic perspectives. The data collected and analyzed for this study were drawn from past reports on batteries, conference proceedings, journal articles, and discussions with U.S. and Canadian representatives from industry, government, and academia. Appendix A contains a material database noting the information sources used for this study.

The study group developed a site selection criteria matrix to identify the most important sites to visit. The matrix listed battery producers, their location, the commercial and military battery types they produce, their unit and sales volume, the percentage of business devoted to military work, the percentage of business devoted to commercial work, and their customers. This matrix is included as Appendix B. The study group first selected sites that would provide coverage of the battery chemistries and types. Where there were multiple suppliers of the same battery type, selection was based on volume and business with the individual Services, taking into account market niche, emerging and evolving battery technologies, battery applications, product technology development, research, development, testing and evaluation, and system impact. Sites then were organized geographically so that trips could be scheduled efficiently. Appendix C lists sites visited and contacted.

Other facilities in the battery arena, such as testing and academic R&D laboratories, were identified and selected in conjunction with the Battery Working Group separate from the site selection process. Decisions were based on level of battery research activity, specific areas of concentration, and particular areas of expertise.

When it was determined that an industry, university, or government site was not to be visited, a more extensive phone interview was conducted. The study group prepared data collection guidelines to facilitate obtaining data from all points of contact either through telephone interviews and/or site visits. Two separate packages were prepared - one for manufacturers/ suppliers and one for research and development facilities. These are included in this report as Appendix D and E.

Site visits were conducted in five regional trips: Midwest, West Coast, Southeast, Northeast, and Southeast Canada. Prior to each regional trip, phone interviews were conducted

with identified representatives from the region to collect preliminary background information on each site to be visited. A one page program overview and data collection guideline package was forwarded to each site prior to the visit to provide the organization with an understanding of the goals of the battery sector study and the type of information being sought.

Site visits began by providing site personnel with an overview of the battery study; information on how and why the NADIBO selected the battery sector to study; the goals, objectives, and scope of the study; the estimated completion date of the study; and the basic goals and objectives of the site visit. During each site visit, specific information was collected regarding the organization's activities within the industry, their financial viability, their current research and development activities, and their opinions on technology trends, health of the industry, current and potential problems, impediments to industry advancement, and steps to maintain the sector's continued viability and advancement.

Data collected from relevant documents, site visits, and phone interviews were analyzed and incorporated into a report. This report functioned as a working document throughout the data collection phase of this study and served as an information database for the completion of this document.

6.0 TECHNICAL DESCRIPTION OF THE BATTERY SECTOR

This section provides a technical description of the battery sector. It includes a definition of a battery and descriptions of selected battery chemistries important to military applications. For each battery chemistry, a description of the internal chemical reactions during charge and discharge is provided along with advantages and disadvantages of the specific battery chemistry. A description of manufacturing processes, cell configurations, and battery properties is also provided.

6.1 Battery Definition and Characteristics

A battery is a device that converts chemical energy contained in its active materials directly into electrical energy by means of an electrochemical oxidation-reduction (redox) reaction. A redox reaction involves the transfer of electrons from one material to another.

Oxidation is defined as the removal of electrons from an atom or group of atoms while reduction is the addition of electrons to an atom or group of atoms. Oxidation occurs at the anode; it gives up electrons to the external electrical circuit. Reduction occurs at the cathode; it accepts electrons from the external electrical circuit.

When a battery stands idle after discharge, chemical and physical changes take place which can result in voltage recovery. Thus the voltage of a battery which has dropped during a heavy discharge will rise after a rest period.

The temperature at which the battery is discharged has a significant effect on its service and voltage characteristics. This is due to the reduction in chemical activity and to the increase in the internal resistance of the battery at lower temperatures.

Power density refers to the amount of power per unit weight or per unit volume. For batteries, this measurement is expressed in either watts per kilogram (W/kg) or watts per liter (W/l). These units are an important figure of merit for portable and transportable systems.

Batteries are a perishable product and deteriorate as a result of chemical action that occurs during storage. The shelf life of the battery is a function of the type of battery, design, and chemical composition, but since self-discharge proceeds at a lower rate at reduced temperatures,

refrigerated storage extends the shelf life. However, refrigerated batteries should be warmed before discharge to obtain maximum capacity.

6.2 Battery Components

The basic unit of a battery is the cell. A battery contains one or more cells connected in series, parallel, or series-parallel, as shown in Figures 6-1, 6-2, and 6-3. Their configuration determines the output voltage and capacity. Battery discharge rate is usually expressed in terms of "C" rate. Discharge rate has the units of amperes. C is the battery capacity in units of ampere-hours (Ah). The discharge rate is expressed as the number of hours required for complete discharge divided into the measured (or rated) capacity. Figure 6-4 depicts the components and operation of a battery.

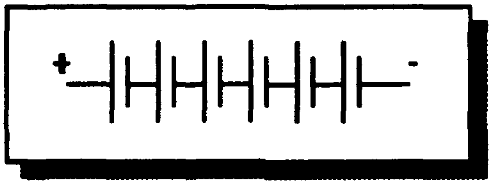

Figure 6-1. Battery Cells in Series

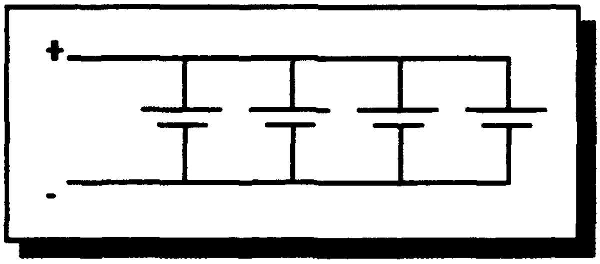

Figure 6-2. Battery Cells in Parallel

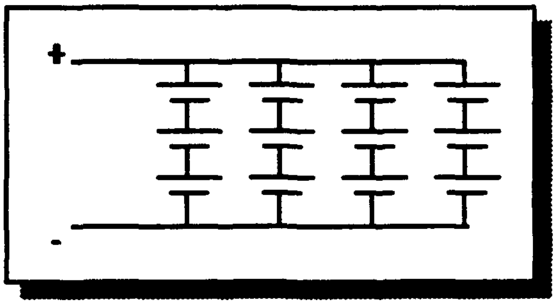

Figure 6-3. Battery Cells in Series-Parallel

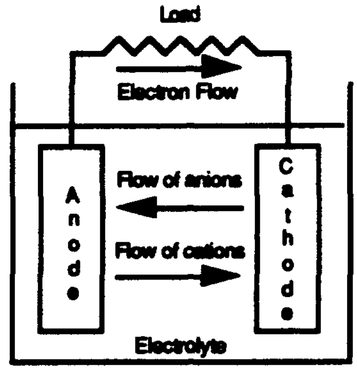

Figure 6-4. Battery Components and Operation

Cells arranged in a parallel configuration provide increased current. Cells arranged in a series configuration provide a voltage higher than the individual cell voltage. Cells connected in a series-parallel configuration are used when the desired voltage/current combination is not available in individual series or parallel configurations.

The terms battery and cell are often used interchangeably. A cell is the actual composition of an anode, cathode, electrolyte, and separator. A battery is the combination of cells or an individual cell (e.g., alkaline D cell battery).

There are three major components of a cell:

(1) **Electrodes.** The electrodes are the heart of the cell. A cell has a positive and a negative electrode. The electrodes are composed of some type of structural member (the grid), a current collector to conduct the current to and from the electrode, and an active material for the oxidation-reduction reaction. The electrodes directly determine the capacity and, usually, the life to be achieved by the cell.

The positive electrode accepts electrons from the external circuit. This is where the reduction reaction takes place during discharge. The negative electrode gives up electrons to the external circuit. This is where the oxidation reaction takes place during discharge.

The cell is usually constructed with multiple positive plates connected in parallel and multiple negative plates also connected in parallel with adequate separation between interleaved positive and negative plates. This type of design minimizes cell internal electrical resistance in

order to maximize power capability at good ampere-hour yields and provides for a compact geometric form.

(2) **Electrolyte.** The function of the electrolyte is to carry electric current between the sites of the reduction reaction and the oxidation reaction by means of charged particles called ions when an external electron path is provided between the two reactants.

The electrolyte is the ionic conductor; it is the medium for transfer of electrons, such as ions, inside the cell and between the electrodes. The electrolyte is usually in the form of liquid, solid, or gel.

(3) **Separator.** The separator is a porous membrane placed between the electrodes to prevent the electronic contact of the electrodes. If plates make contact, electrons flow directly from the negative to the positive plate; the cell becomes internally short-circuited and cannot produce outside electrical energy. The separator must have the capability of permitting ionic flow or electrical current cannot flow. There must be a complete electrical circuit.

6.3 Classification of Batteries

6.3.1 Classification by Storage Capability

There are three battery charge storage classifications: primary, primary reserve, and secondary.

6.3.1.1 Primary Batteries

Primary batteries cannot easily be recharged electrically and are therefore known as non-rechargeable batteries. They are discharged once and discarded. Primary batteries are characterized by good shelf life, high energy densities, low maintenance, and ease of use. Primary batteries most often used in military applications include dry cells, thermal, lithium, and some magnesium.

6.3.1.2 Primary Reserve Batteries

Primary reserve batteries differ from primary batteries in that a key component is separated from the rest of the battery until it is activated. The key component that is isolated is usually the

electrolyte. This type of battery is capable of long-term storage and can withstand environmentally severe storage requirements. Reserve batteries are used primarily to deliver high power for relatively short time periods after activation and are often an integral component of an end item and cannot be replaced.

Primary reserve batteries are activated by adding the missing component just prior to use. In a simple design, this is done by either manually pouring the electrolyte into the cell or placing the battery into the electrolyte. In more sophisticated designs, the electrolyte storage and the activation mechanism are contained within the same battery structure. Once the activation mechanism is engaged, the electrolyte is automatically brought into contact with the active components.

6.3.1.3 Secondary Batteries

Secondary batteries can be recharged electrically after discharge to their original condition, thus being termed rechargeable batteries. This is accomplished by passing current from a power source through the battery in the opposite direction of the discharge current. Secondary batteries are characterized by high power density, high discharge rate, rechargeability, and good low-temperature performance. Two types of rechargeable batteries most commonly used in military applications are lead acid and nickel cadmium.

Table 6-1 presents battery characteristics specific to rechargeable and non-rechargeable battery types.

Characteristic	Rechargeable	Non-Rechargeable
Cycling	X	
Long Life	X	
Low Cost	X	X
Low Weight		X
Low Maintenance		X

Table 6-1. Battery Characteristics

6.3.2 Classification by Chemistry

The following sections discuss the seven common chemistry families as discussed throughout this report: thermal, lithium, mercury, silver, lead acid, nickel cadmium, and magnesium.

6.3.2.1 Thermal

Thermal batteries are a type of reserve primary battery. They employ a molten salt electrolyte which is solid at ambient temperatures when the battery is inactive; in this state, the electrolyte is nonconducting and the battery is inert. The cell is activated by heating it to a temperature high enough to melt the electrolyte permitting the flow of current. The battery can be stored for periods of 10 plus years in an inactive state but the operation life of the thermal battery is short. The solid electrolyte protects the active cell components from corrosion and self-discharge during storage. Thermal batteries are classified as reserve batteries for the above reasons.

Figure 6-5 shows the configuration of a lithium-iron disulfide thermal battery cell. It is composed of thin, circular wafers arranged in layers:

1. an anode wafer of lithium alloy as the negative electrode
2. an electrolyte/separator wafer of molten salt mixed with an inorganic gelling agent
3. a catholyte wafer of iron disulfide mixed with some electrolyte as the positive electrode (cathode)
4. a pyrotechnic heat source wafer of iron powder mixed with potassium perchlorate which collects current on the cathode

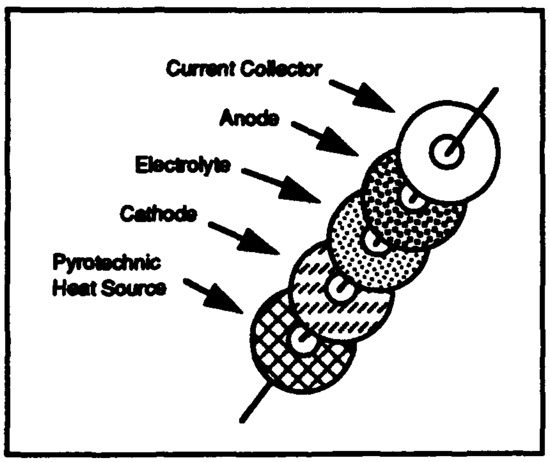

Figure 6-5. Lithium Iron Disulfide Thermal Battery Configuration

The powdered materials are compressed to form the wafers. The electrolyte is composed of an eutectic mixture of lithium chloride and potassium chloride salts. The thermal cells are placed in hermetically sealed, steel battery cases to provide protection from humid air during storage. The hermeticity of this seal is a critical determinant of the shelf life of thermal batteries. The cells of the battery are arranged in series and are surrounded by fibrous ceramic insulation.

6.3.2.2 Lithium Family

Lithium batteries use lithium metal as the negative (anode) active material. The type of lithium battery is determined by the positive electrode (cathode) active material. There are four main types of lithium primary batteries:

- solid cathode
- liquid cathode
- solid electrolyte
- reserve

Solid cathode cells use a solid positive active material and an organic electrolyte. These cells are manufactured in the coin and cylindrical configurations. Lithium thionyl chloride and lithium sulfur dioxide cells use a liquid cathode material. The liquid cathode material serves as the active cathode material and as the solvent for the electrolyte. They are manufactured mainly in cylindrical, bobbin, prismatic, and spiral-wrap configurations. Solid electrolyte batteries are composed of solid components and a solid ion conducting electrolyte. These types of electrolytes offer low conductivity compared to most liquid electrolytes.

Special attention is given to the design and use of the lithium battery because it contains materials that are potentially flammable and toxic. Properly designed cells are equipped with safety vents which release gases when the cells reach high temperatures and pressures—preventing explosive damage. Vents, however, are used only on high discharge rate cells; low and medium rate cells do not require vents. Lithium batteries offer several favorable features such as:

- long shelf life
- good high and low temperature performance
- high power density
- high voltage
- light weight

There are several types of primary and secondary lithium batteries used currently in military applications or used as prototype batteries in other applications:

- lithium sulfur dioxide
- lithium manganese dioxide
- lithium thionyl chloride
- lithium ion

These battery types are discussed in the following sections.

6.3.2.2.1 Lithium sulfur dioxide

The lithium sulfur dioxide ($LiSO_2$) battery is the most common and well-developed lithium primary cell. The battery is constructed of a lithium (Li) anode, a sulfur dioxide (SO_2) cathode, and acetonitrile and lithium bromide as the electrolyte. The cell reaction is as follows:

$$2Li + 2SO_2 \longrightarrow Li_2S_2O_4$$

The cell is typically fabricated in a cylindrical structure. A "jelly-roll" configuration is used, made by spirally winding strips of lithium ribbon, a polypropylene separator, and the cathode electrode. This design provides the high surface area and low cell resistance necessary to obtain high-current and low-temperature performance. The roll is inserted in a steel container that is electrically connected to the anode. The cathode is connected to its terminal and the cell is hermetically sealed—tightly sealed so that air cannot enter or escape.

The lithium sulfur dioxide battery is a standard Army battery which is characterized by:

- mature technology
- safe
- reliable
- shelf life of 10 plus years
- performance in all temperatures

6.3.2.2.2 Lithium manganese dioxide

The lithium manganese dioxide ($LiMnO_2$) battery is constructed of a lithium (Li) anode and a manganese dioxide (MnO_2) cathode. The electrolyte is propylene carbonate/dimethoxyethane. The cell reaction during discharge for this primary battery is:

$$Li + Mn^{IV}O_2 \longrightarrow Mn^{III}O_2(Li)$$

The lithium manganese dioxide battery is characterized by:

- highest safety
- potentially lowest cost
- early development stages

6.3.2.2.3 Lithium thionyl chloride

The lithium thionyl chloride ($LiSOCl_2$) battery is another of the lithium primary batteries. This battery is composed of a lithium (Li) anode, a thionyl chloride ($SOCl_2$) cathode, and a lithium tetrachloral in thionyl chloride electrolyte. The chemical reaction during discharge is:

$$4Li + 2SOCL_2 \longrightarrow 4LiCl + SO_2 + S$$

The thionyl chloride is capable of forming a resistant film on the lithium anode. This film, which forms at particularly high-temperature storage, is not readily penetrated and excessively long voltage delays occur in a high rate and low temperature discharge environment. The thionyl chloride cell exhibits good shelf life and has been designed as a low discharge-rate cell using a bobbin construction.

The lithium thionyl chloride battery is characterized by:

- high power
- performance at all temperatures
- unknown shelf life

6.3.2.2.4 Lithium ion

The lithium ion battery is a secondary battery which provides high energy density, high cycle life, and safety over other lithium rechargeable batteries. It is a fairly new system -

introduced by Sony in 1990. The battery is constructed with a carbon (C) anode, a lithiated cobalt oxide (CoO) cathode, and an organic propylene carbonate electrolyte. The chemical reaction during charge and discharge is as follows:

$$LiC_6 + CoO_2 <\!\!-\!\!> Li_{1-x}C_6 + Li_xCoO_2$$

In 1993, a new type of rechargeable battery was unveiled - known as the "rocking chair" battery - in which lithium ions shuffle between a lithium manganese oxide electrode and a carbon electrode. This new, still experimental battery has many advantages over other lithium ion batteries. The new battery is safer, longer lasting, and potentially cheaper to manufacture. The battery is known as the "rocking chair" battery because of the back and forth movement of the lithium ions during the charge and discharge. The battery is charged when lithium ions are released from the cathode and flow to the anode.

6.3.2.3 Mercury

Mercury batteries are composed of a zinc (Zn) anode, a cathode of mercuric oxide (HgO) mixed with graphite, and a potassium hydroxide (KOH) electrolyte. The cell reaction for the mercury battery during discharge is:

$$Zn + HgO \longrightarrow ZnO + Hg$$

In a steel container, the active materials are separated by a porous material which prevents migration of conducting particles from the mercuric oxide pellet. Mercury batteries are constructed in a flat pellet structure, a cylindrical structure, and the wound anode flat structure.

The mercury batteries are constructed in a sealed but vented structure; the active materials are balanced to prevent formation of hydrogen in a discharged battery. The battery has three basic structures: (1) wound, (2) flat-pressed, and (3) cylindrical.

The mercury batteries are characterized by high energy-to-volume ratio and long shelf life. They have a high electrochemical efficiency and are mechanically rugged. Mercury batteries are also well known for their very flat discharge curve. However, mercury batteries tend to be expensive and present disposal problems. They also are plagued by electrolyte seepage after long storage period.

6.3.2.4 Silver Family

The silver oxide zinc batteries, both primary (non-chargeable) and secondary (rechargeable), and the silver cadmium batteries, secondary, are used in military applications.

6.3.2.4.1 Silver oxide zinc

The silver oxide zinc (referred to in this report as silver zinc) battery is composed of a pressed or pasted zinc (Zn) powder for the anode and silver oxide (AgO/Ag_2O) for the cathode. Aqueous potassium hydroxide (KOH) is the electrolyte for this battery. The cell reaction during charge and discharge is:

$$Zn + Ag_2O + H_2O \longleftrightarrow Zn(OH)_2 + 2Ag$$

During charge, the silver is reoxidized and the zinc is plated out on the negative plate. During discharge, the reverse action occurs.

This cell is normally constructed in a rectangular shape using flat plates. The positive plates are made by pressing or sintering silver or silver oxide powder onto a silver grid or screen and then electrochemically converting the silver to silver oxide. The negative plates are made by pressing zinc or zinc oxide onto a silver or copper grid and then forming or converting the material to zinc. The plates are intermeshed and the resulting cell is placed in a tightly fitting plastic case.

6.3.2.4.2 Silver cadmium

The silver cadmium (AgCd) battery is composed of a cadmium (Cd) anode and a silver oxide (AgO) cathode. As in the silver oxide/zinc battery, aqueous potassium hydroxide (KOH) serves as the electrolyte. The cell reaction during charge and discharge is:

$$Cd + Ag_2O + H_2O \longleftrightarrow Cd(OH)_2 + 2Ag$$

The negative electrode (anode) becomes oxidized when discharged and is converted to metal when fully charged. The silver electrode (cathode) is oxidized during charge first to silver monoxide then to silver dioxide. This is the state of the fully charged cathode.

Silver cadmium cells have a limited cycle life because there is a slow cadmium penetration through the separators. However, silver cadmium batteries offer a better cycle life than the silver zinc cells because of the stability of the cadmium.

6.3.2.5 Lead Acid

The lead acid battery is the most widely used secondary battery. It is characterized by low cost, reliability, and good performance characteristics. The lead acid battery is composed of a sponge lead (Pb) anode, a lead dioxide (PbO_2) cathode, and an aqueous sulfuric acid electrolyte. The cell reaction for the lead acid battery for charge and discharge is:

$$Pb + PbO_2 + 2H_2S0_4 \longleftrightarrow 2PbSO_4 + 2H_2O$$

During discharge, the active materials of both electrodes are converted into lead sulfate ($PbSO_4$). The electrolyte takes part in the reaction by producing water. During charge, the lead sulfate in the positive electrode is converted to lead dioxide (PbO_2) and the lead sulfate in the negative electrode is converted to sponge lead. At the end of the charge, electrolysis of the water also occurs, thus producing hydrogen at the anode and oxygen at the cathode.

The most common construction for the lead acid cell is the pasted-plate design. The active material for each electrode is prepared as a paste by mixing finely divided lead oxides and suitable expander materials with sulfuric acid. The paste is spread onto a lead-alloy grid which provides the necessary electrical conductivity and structure to hold the active materials. The plates are then soldered to connecting straps to form positive and negative groups which are interleaved. Separators are placed between the electrodes, and the completed assembly is placed in a container. The container is designed with a sediment space under the stack assembly to safely collect any of the active material that sheds. Sufficient headroom is provided above the plates to hold excess electrolyte.

A new lead acid battery technology contains limited amounts of free liquid electrolyte. This is referred to as an absorbed glass mat lead acid battery. Liquid electrolyte is placed into the battery and allowed to dry. After time, the dried electrolyte will crack. Ionic flow occurs through cracks in the dry internal plates between the cathode and anode. The advantage of this type of cell is that orientation is not a concern. The battery can be placed in different positions without the fear of electrolyte insufficiently saturating the electrodes.

6.3.2.6 Nickel Family

Nickel cadmium secondary rechargeable batteries are widely used in military applications. The nickel cadmium battery features:

- high power capability
- long cycle life
- good low-temperature performance
- ruggedness
- reliability

The nickel cadmium battery is manufactured in many sizes ranging from the small sealed button and cylindrical cells to larger vented cells.

6.3.2.6.1 Nickel cadmium

The nickel cadmium battery is composed of a cadmium (Cd) anode and a trivalent nickel oxide (NiOOH) cathode. The electrolyte is aqueous potassium hydroxide. The cell reaction is as follows:

$$Cd + 2NiOOH + 2H_2O \longleftrightarrow Cd(OH)_2 + 2Ni(OH)_2$$

During discharge, the nickel oxide is reduced and the cadmium is oxidized. Near the end of charge, hydrogen is formed at the positive electrode and oxygen at the negative as the cell reaches full charge. There is no change in the electrolyte concentration.

The nickel cadmium battery is known for its light weight, good cycle life, high energy density, and improved performance over nickel iron batteries. Nickel cadmium batteries experience memory effect, sometimes called the hysteresis effect. Essentially, the battery "forgets" its full capability if it is not discharged extensively from time to time.

The original construction configuration used for the nickel cadmium cell was the pocket-plate construction. In this design, the active materials are in powdered form and are contained in perforated rectangular pockets formed from thin perforated nickel-plate steel ribbon. The perforated pockets are welded onto steel frames to form electrodes of various sizes and capacities. The perforations allow access of the electrolyte. The positive and negative plates are bolted together in an insulated fashion and assembled in a plastic or nickel-plated steel container. The

pocket-type cells are very rugged and can withstand electrical as well as mechanical abuse. They have very long life and require little maintenance beyond occasional fill-up with water.

The sintered-plate cell design has a higher energy density and gives better performance than the pocket type but is more expensive. A sintered plate is fabricated from three components:

1. a nickel or nickel-plated steel grid
2. a porous sintered structure surrounding this grid
3. the active material in the porous structure

The porous sintered plaque is prepared by sintering a fine nickel powder onto the grid. The active materials are impregnated in the pores of the plaque and converted to the active materials. The cell components are then assembled, alternating positive and negative plates with a separator in between. The separators consist of sheets of nylon cloth with thin, films such as cellophane or celgard to prevent gas diffusion and the recombination of oxygen with the negative electrode.

The sealed nickel cadmium is available in several constructions. Rectangular cells are constructed in essentially the same fashion as the vented cell, except that the rectangular cell incorporates specific design features to prevent the pressure buildup caused by outgassing during charge. These features include:

1. Excess negative capacity, by which the positive plate reaches full charge before the negative plate.
2. A separator permeable to oxygen so it can pass through to the anode.
3. A limited or starved electrolyte to facilitate the transfer of oxygen.

The cylindrical cell is constructed of sintered-type electrodes. The electrodes are interleaved with the separator, in a "jelly-roll" fashion, and inserted in a nickel-plated steel can. Small button cells are made from sintered or pressed plates.

6.3.2.7 Magnesium

The magnesium battery is characterized by a long service life and the ability to retain a large capacity during storage. It is a primary battery.

The magnesium cell is constructed of a magnesium (Mg) alloy anode and the cathode is a combination of manganese dioxide, acetylene black, magnesium perchlorate electrolyte, barium and lithium chromate, and magnesium hydroxide. The cell reaction is as follows:

$$Mg + 2MnO_2 + H_2O \longrightarrow Mn_2O_3 + Mg(OH)_2$$

The amount of water in the battery is critical as water participates in the anode reaction and is consumed during the discharge. Sealing of the magnesium cell is critical, as it must be tight to retain cell moisture during storage but provide a means for escape of hydrogen gas that forms as the result of a parasitic reaction during the discharge of the battery.

The magnesium battery is constructed of a cylindrical magnesium container as the negative electrode and manganese dioxide as the positive element. A paste or paper separator separates the two electrodes. The magnesium cell has a mechanical vent so that hydrogen gas can escape from the battery during discharge.

6.4 Battery and Cell Manufacturing

6.4.1 Cell Manufacturing

Cell design and manufacture comprises several high level steps. The first step is to design the electrodes. The size of the positive electrode depends on the desired capacity. The size (thickness) of the negative electrode depends on the amount of active material needed to electrochemically balance the active material in the positive electrode. Electrodes are constructed of an active material and a grid - some type of structural member. The grid is manufactured of material specific to the type of cell being manufactured. For instance, grids used in lead acid cells are constructed of lead alloy and grids used in nickel cadmium cells are constructed of either nickel metal or nickel plated steel.

Separators have many purposes, depending on the type of battery. Their main purpose is to prevent the plates from touching and electrically shorting. They also hold electrolyte and allow passage of ions and gases in sealed cells. In vented cells, the separator prevents the passage of gases. They are made of different materials, depending on the type of battery. For example, separators used in a lead acid battery usually are made from a microporous rubber material or a microporous polyethylene material. Separators in a sealed nickel cadmium battery are made of

non-woven (felt) nylon. In vented nickel cadmium cells, the separator is usually woven or non-woven nylon or polypropylene.

The electrolyte is an active part in the chemical reactions that produce energy from the cell. In most cell designs, the electrolyte is available as a free liquid in which the plates are immersed. In sealed cells, sufficient electrolyte is present to moisten all internal components with little or no "free" electrolyte. This is known as the starved electrolyte design. It allows oxygen gas generated at the positive electrode to migrate to the negative electrode. Vented cells contain an excess of electrolyte—also known as flooded cells. The resealable vents allow the escape of gases generated on charge, along with a small amount of water.

Batteries such as lead acid or nickel cadmium are typically designed with vents. As a battery is charged, gas is generated that must be allowed to escape. Venting avoids pressure buildup that could result in cracking of the container and spillage of electrolyte. Valve-regulated cells incorporate a pressure relief valve. These batteries do not vent unless internal pressure has exceeded the design pressure of the valve. When the pressure falls, the valve closes and reseals.

The battery container/case holds the cells in place during use and handling. Containers range from a simple shrink wrap sleeve for button and cylindrical cells to a machined and fabricated complex structure for aerospace cells. Depending on the application, the container may have a removable cover or be a sealed unit. In the case of some vented cells, the cover must be removable so water can be added periodically. Containers can be made of stainless steel, high-impact rubber, a variety of plastics, or nylon, among others. The container must be designed to withstand, without distortion beyond the recommended dimensions, the internal pressure exerted by the elements, the electrolyte, and cell gases during service use or factory processing. Wall thickness varies depending on the material selected for the container.

6.4.2 Cell Configurations

Cells are configured in different shapes and sizes - cylindrical, button, and prismatic. Cylindrical cells are available in four different sizes: AAA, AA, C, and D, as shown in figure 6-6. Table 6-2 lists the minimum and maximum dimensions for the cylindrical cell batteries shown in the figure.

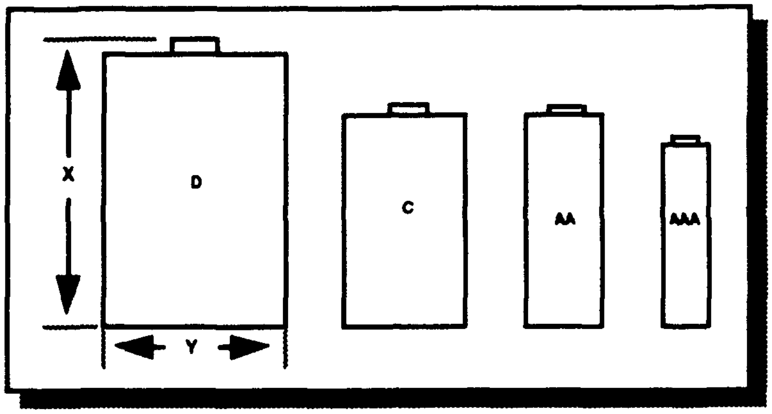

Figure 6-6. Cylindrical Cell Configurations

SIZE	DIMENSION (mm)			
	X		Y	
	MAX	MIN	MAX	MIN
D	61.5	59.5	34.2	32.2
C	50	48.5	26.2	24.7
AA	50.5	49	14.5	13.5
AAA	44.5	42.5	10.5	9.5

Table 6-2. Cylindrical Cell Dimensions

Figure 6-7 depicts a typical cylindrical cell assembly process. In this figure, strips of the anode material, separator, and cathode material are spirally wound resulting in a "jelly-roll" configuration. The roll is inserted into a steel container which is electrically connected to the anode. The cathode is connected to the terminal and the cell is hermetically sealed. The jelly-roll configuration is characterized by a high discharge rate (current).

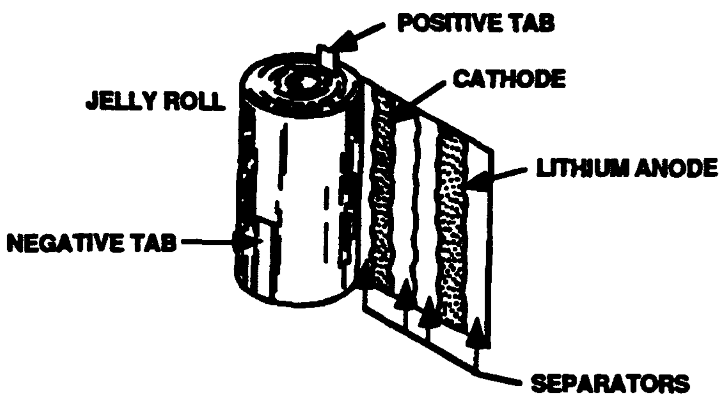

Figure 6-7. Cylindrical Cell Assembly

Another type of cylindrical configuration is the bobbin configuration, as shown in figure 6-8. In this process, a cylinder is created from the anode material. The cylindrical anode is rolled into a separator and then inserted into a tubular cathode. The tube is then inserted into the container and filled with electrolyte. The bobbin configuration is characterized by a low discharge rate (current).

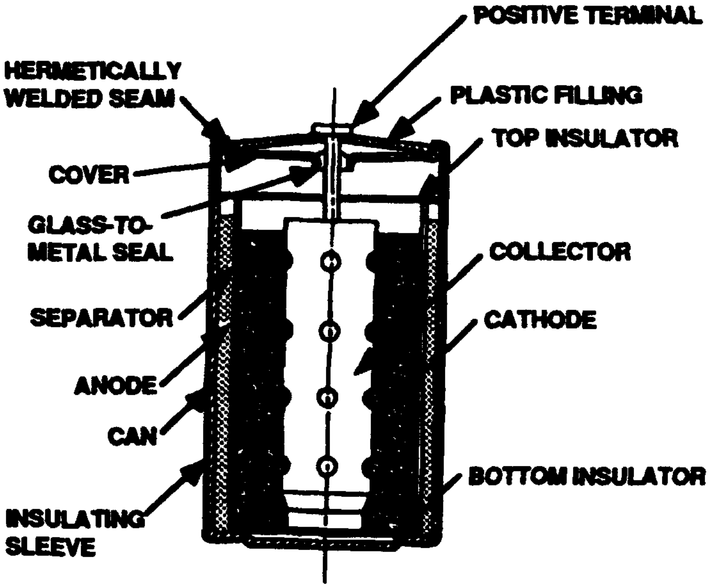

Figure 6-8. Cylindrical Cell Bobbin Configuration

A typical button, or coin, configuration is depicted in figure 6-9, and a prismatic configuration is depicted in Figure 6-10.

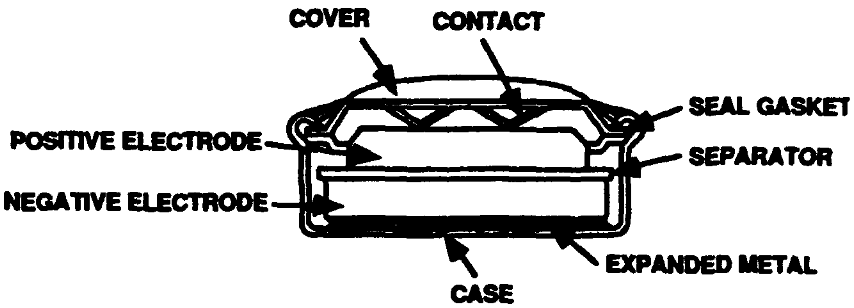

Figure 6-9. Button Cell Configuration

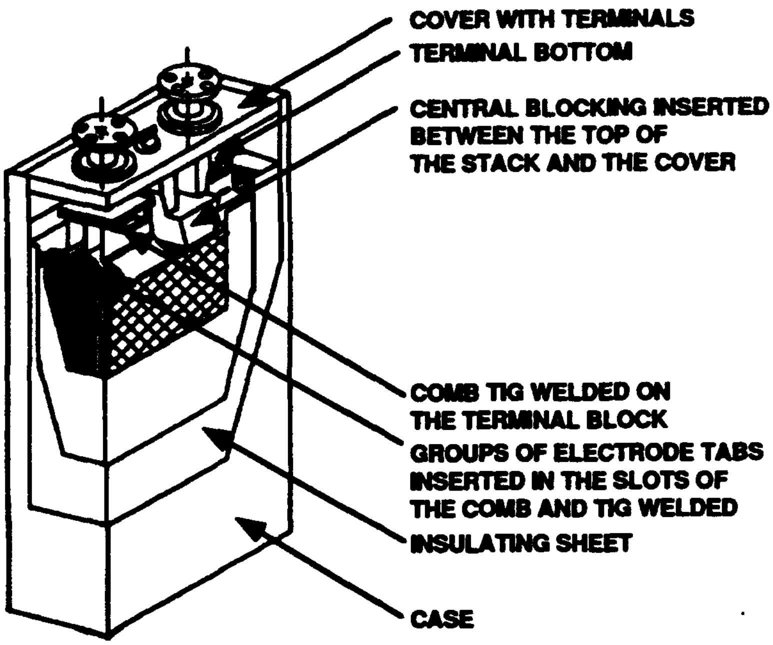

Figure 6-10. Prismatic Cell Configuration

6.4.3 Cell Repackaging

As mentioned earlier, a battery is actually a collection of cells even though the terms often are used interchangeably. When two or more cells are placed into a container or case, they must be properly connected to ensure both performance and reliability of the finished battery. The choice of connection depends on the performance requirements and cost. There are several types of connections: bolted, soldered, welded, and pressure.

Bolted connections are used for heavy-current applications. The connections are made with bolts and lockwashers on threaded terminals with controlled tightening torque. Materials such as lead alloy, lead-plated copper, stainless steel, or nickel-plated steel are recommended for this type of connection.

Soldering is performed on the leads of the cells. Soldering is not performed directly on the cell since this will cause local overheating of the cell. A wire lead is not soldered directly onto a

cell because the heat may damage internal components. Usually a metal intercell connection (tab) is spot-welded to the cell; this connection may have a wire lead soldered to it.

Spot welding is another form of intercell connection. Spot welding is preferred to soldering because it reduces the amount of heat that the battery is exposed to.

Pressure connections usually employ a spring or some other device to compress one or more cells. This method is used in small sealed cells. The springs are fabricated of spring brass, beryllium copper, steel plated with nickel or silver, or other material. Pressure connections may be less reliable than soldering or welding.

After the cells are connected with one of the methods mentioned above, they are either shrink wrapped (for protection) or placed in some type of container/case. Section 6.4.1 discusses the different materials that can be used for the containers.

6.5 Battery Properties and Characteristics

6.5.1 Battery Properties

Table 6-3 depicts several existing and research and development (R&D) battery chemistries and their associated properties. Open circuit voltage refers to the cell voltage when no current is flowing; the closed circuit voltage is the voltage when current is flowing.

Battery Chemistry	Voltage (V)		Ampere Hours (Ah)	Shelf Life (years)	Primary/ Secondary	Self-Discharge %/mo.	Specific Power (W/kg)
	Open	Closed					
Lithium Sulfur Dioxide (Li/SO_2)	3.00	2.70	40	10	primary	0.03	250
Lithium Sulfur Dioxide (Li/SO_2)	3.30	3.10		3	secondary (R&D)	0.01	160
Lithium Thionyl Chloride ($Li/SOCl_2$)	3.70	3.40	10000	15	primary	0.03	400
Lithium Manganese Dioxide (Li/MnO_2)	3.00	2.80	25	10	primary	0.50	230
Lead Acid (VRLA)	2.15	1.98	up to 4000	20	secondary	0.03	200
Silver Oxide/Zinc (Ag/Zn)	1.86	1.55		2	primary / secondary	0.05	140-180
Silver Cadmium (Ag/Cd)	1.41	1.10		3	secondary	0.05	400
Nickel Cadmium (Ni/Cd)	1.35	1.20	up to 2000	20	secondary	0.15	260

Table 6-3. Properties of Common Batteries

Lithium primary batteries offer high voltage ranges, typically 2.5 to 3.5 volts; high energy density; high power density; flat discharge characteristics; and one of the best storage lives. This translates into power systems that are lighter weight, lower cost per unit of energy, and have

higher and more stable voltages. Some lithium cells are designed for low-rate applications, using the bobbin configuration. These cells offer high energy outputs.

Nickel cadmium batteries have a comparable power output to the lithium primary batteries but lower voltage ranges. The silver cadmium battery has voltage ranges similar to the nickel cadmium battery but higher power output. Primary and secondary silver zinc cells have moderate voltage ranges and a short shelf life of only two years. However, primary reserve silver zinc cells can have shelf lives up to twenty years.

The type of battery used for a particular system depends on the system requirements. The following characteristics are considered when selecting a battery for a particular application:

- function
- operating environment
- electrical requirements
- weight
- volume
- life
- life cycle cost
- maintainability
- reliability
- safety

6.5.2 Battery Characteristics

Different manufacturing processes for batteries provide differing characteristics. For example, a lead acid battery can be flooded, valve-regulated, or sealed. A flooded, or conventional, battery loses water and hydrogen during charge. This dictates periodic water replenishment. However, in valve-regulated and sealed lead acid batteries, there is no water loss during charging and no water replenishment is necessary.

As mentioned in Section 6.3.2.6.1, nickel cadmium (NiCd) batteries are manufactured in vented pocket-plate, vented sintered-plate, or sealed configurations. Each of these configurations offers different characteristics. A vented pocket-plate Ni/Cd battery has a long shelf life; is rugged; can withstand electrical (overcharging, shorting) and mechanical abuse; has good charge retention; and can be stored filled or unfilled (with electrolyte) for long periods of time without deteriorating. Several of the characteristics also are inherent to the vented sintered-plate Ni/Cd battery; however, the vented sintered-plate has a higher energy density than the vented pocket-plate and has lower internal resistance. Both batteries require little maintenance, aside from the necessary water replenishment.

The sealed nickel cadmium battery requires no water addition or electrolyte renewal and can operate in any position. This is advantageous due to the restricted areas in which batteries must be used in military applications. However, its performance is inferior compared to that of the vented sintered-plate configuration.

7.0 MARKETPLACE DESCRIPTION AND TRENDS

This section describes the North American battery production industrial base and presents trends that provide an indication of its future evolution. It is presented in two parts: the first presents battery marketplace concerns; the second discusses the manufacturing companies that supply batteries to the U.S. and Canadian governments. Battery manufacturers that strictly produce products for the commercial market are not discussed. These commercial, mass-produced batteries include commonly recognized single or button cell batteries or the common alkaline batteries used for commercial products like children's toys, watches, clocks, and audio equipment. These batteries have chemistries similar to those discussed in this study, but military and government batteries have different configurations and specifications.

7.1 Battery Marketplace Concerns

In discussions with battery manufacturers, researchers, and military users, several marketplace concerns were commonly raised. These included the approach to battery selection/design in new systems, common battery logistics systems in the U.S. and Canada, tracking and accessing battery performance and configuration characteristics, battery procurement procedures, battery maintenance procedures, and environmental concerns. Each of these is discussed in the following paragraphs.

7.1.1 Planning for Power Requirements

Power source requirements for a system are among the last considerations of system designers. Because of this, batteries often are designed to fit in the remaining space within the system envelope, resulting in the widespread proliferation of military-unique, system-unique batteries. If the design process were constrained to use batteries from a fixed set of options suitable to the application, with deviations subject to waiver requests, system planners could capitalize on dual use chemistries, standardize the selection of batteries used to families or configurations within each chemistry, and reduce the number of military-unique, system-unique batteries.

7.1.2 Military Specifications and Standards

Supporting military specifications and standards may impact ancillary manufacturing processes involved in battery manufacturing These specifications ensure that procedures such as

shipping and packaging of the batteries will meet certain requirements. However, some of these supporting specifications are outdated and in need of revision. Packaging and shipping of batteries are a prime example. One battery producer indicated they were required to ship their batteries in wooden crates. This was an expensive undertaking that added to the overall battery cost and did not allow the producer to take advantage of newer, more cost effective materials.

7.1.3 Assignment of Battery NSNs (NATO/National Stock Numbers)

When a new battery is designed, it generally is assigned a National Stock Number (NSN). Currently, the U.S. has an estimated 3,500 battery NSNs and Canada over 600 NATO Stock Numbers. In the over 4,000 battery NSNs in North America, duplication exists between the two countries and among the U.S. military Services. There are two reasons for this problem. First, if the U.S. adopts a NSN for a specific battery that has a common application with Canada, the Canadian DND adopts the same number, but if the DND adopts a NSN first, the U.S. does not always adopt the same number. Second, there is incomplete cataloguing and tracking of batteries between the Services; an aviation battery used by the Navy may have one NSN while the same battery from the same manufacturer for the Army may have a different NSN.

In addition, sometimes the battery involved in a major component, e.g., an electronic component, is not given its own NSN. The entire electronic component is assigned an NSN rather than the individual pieces. Tracking the batteries used in such items, such as the battery in the Trident missile, is difficult to accomplish.

7.1.4 Documentation and Tracking of Batteries

The successful documentation and tracking of batteries would help in reduce the proliferation of new batteries within the military. If battery designers access a database that can inform them of existing batteries that can fulfill their power needs, the development of new, military-unique, system-unique batteries can be curtailed.

Currently several databases contain information on batteries. In particular, a battery database the Naval Surface Warfare Center at Crane, Indiana includes information on existing cells and batteries. This database is designed to allow the user to choose from a variety of battery attributes as well as combinations of those attributes to identify an existing battery. The database includes information such as battery type (primary, secondary, reserve), battery chemistry, battery specifications (e.g., size, weight, volume), and battery manufacturer. However, this system is not

yet fully populated and is not readily available to battery designers, Project/Program Managers, and procurement personnel. In addition, not all of the targeted users know of its existence or how it can aid them.

Another database is run by the Defense Electronics Supply Center as part of the DoD Parts Control Program. Basically, this system allows for the input and inquiry of information and is available for use by military acquisition activities, equipment contractors, and parts suppliers. It contains a list of all parts approved for design selection in a specific contract. Designers provide the center with their battery requirements; the center, in turn, searches the database to find batteries that meet the requirements. This system contains all the battery NSNs.

7.1.5 Procurement of Batteries

There currently are no joint purchasing programs between the Services or with the Canadian DND. Each organization handles the procurement of batteries individually with little or no coordination. In a number of instances, the same batteries are being procured from the same manufacturer. With better procurement planning, the Services and Canadian DND can likely decrease unit costs by purchasing in larger quantities and eliminating distributor premiums.

7.1.6 Battery Maintenance

Certain secondary batteries, such as nickel cadmium and lead acid, require periodic maintenance to perpetuate battery life. Although newer sealed or low maintenance versions of these same batteries require little or no maintenance, a large number of batteries in use by the military mainly for aviation still require maintenance. This maintenance, if properly performed, ensures maximum battery service life and fewer failures. Procedures involved in battery maintenance include adding electrolyte when necessary, deep discharging and recharging of the battery, and replacing (when/where appropriate) damaged or degraded cells.

During the course of this study feedback obtained concerning the maintenance of batteries indicated that battery maintenance is not as frequent or procedurally correct as it should be, thereby costing the military large dollar amounts in shortened battery service life. Reasons for this lack of proper maintenance include inadequate maintenance procedures, inadequate training/education of personnel, over-maintenance (which can be just as detrimental, if not worse, to the battery than under-maintenance), and personnel turnover. This problem could be rectified if proper procedures were in place and enforced.

7.1.7 Environmental Issues

No significant environmental issues affecting the viability of the battery sector were uncovered. Although certain chemistries such as mercury and, in the future, cadmium, may be phased out of production because of toxic components, presently there is an understood cost of compliance with environmental codes that are met by all companies and suppliers. Other, less environmentally unfriendly batteries also have standard procedures and specifications that manufacturers comply with, and these too are accepted as standard operating costs. No organizations cited these as significant concerns or issues

7.2 Battery Producers by Chemistry

The following sections present, by chemistry, battery manufacturers, their specific product(s), their customers, and the systems their products support. The chemistries follow a sequence from military dominated batteries to those batteries which have only a small military market. For example, the first chemistry presented is the thermal chemistry; this battery chemistry is used only for military or government applications. Other chemistries in the sequence are used for both military and commercial applications, and the chemistries towards the end of this section are those which have a larger commercial than military market. For each chemistry a chart illustrates the companies, their parent ownership, their product, and their business breakdown between military and commercial markets. Following each chart is a brief overview of each company listed, describing the company, its products, capabilities, customers, and future outlook.

At the end of each chemistry subsection there is an end user market review and a marketplace trends review. This review presents a chart which shows military and commercial applications for each chemistry and discusses the present state of the market for each chemistry. This includes market demands, primary customers and suppliers, and trends concerning military and commercial markets.

7.2.1 Thermal Batteries

The term thermal battery does not refer to a specific battery chemistry but to a group of electrochemical systems using different chemistries. The most common thermal battery systems are lithium based. The thermal battery is a primary, 'one-shot' battery that is activated

pyrotechnically and lasts from just a few seconds up to a few hours. Thermal batteries are almost completely unique to military applications.

7.2.1.1 Thermal Battery Marketplace Supply

Eagle-Picher's Joplin, Missouri facility is the only remaining North American producer of thermal batteries. SAFT America in Cockeysville, Maryland ceased thermal battery production in December of 1993 and became a R&D facility.

Eagle-Picher Industries Inc. (EPI) is a diversified, multi-national company founded in 1843. They are a worldwide leader in specialty materials and chemicals for the infrared optics, fiber optics, laser, semiconductor, medical equipment, battery, and plastics industries. The Electronics Division was formed in 1964. The Couples Department, which produces batteries, was started originally in 1948 as a derivative of EPI's battery research laboratory, which was started in 1920. The Couples Department was placed under the Electronics Division in 1964. The name Couples derives from the electrochemical couple which, along with the electrolyte, is the basic working system of any battery. The Couples Department has two plants, one in Joplin, Missouri and a second in Colorado Springs, Colorado.

Eagle-Picher's Joplin, Missouri facility is the sole North American manufacturing plant for thermal batteries. In September of 1991 EPI's Joplin facility suffered a major fire that virtually destroyed their thermal battery manufacturing capability. Prior to the fire, EPI supplied 36 DoD programs with thermal batteries utilizing 50% of their capacity. After the thermal facility was rebuilt, capacity utilization increased to 75% in support of a minimum of 33 DoD programs. Presently EPI produces 400,000 cells per month during one eight hour shift, five days per week. Depending on battery complexity and configuration, this equates to approximately 2,000 batteries per month.

7.2.1.2 Thermal Battery Marketplace Demand

Figure 7-1 illustrates typical military applications for thermal batteries. No commercial applications were identified.

Typical Thermal Battery Applications
Military
aircraft ejection seats
countermeasure devices
fuses
guided artillery
mines
missiles
torpedoes

Figure 7-1. Thermal Battery Applications

Thermal batteries are used for applications requiring physical ruggedness, high power, long storage life without maintenance, and one time use. The thermal battery market is almost completely limited to military applications. Thermal batteries are used in missiles, torpedoes, aircraft emergency systems, guided bombs, and land and underwater mines.

7.2.1.3 Thermal Battery Marketplace Trends

Thermal battery demands are significantly lower than in the past. Programs utilizing thermal batteries and deliveries supporting these programs have been reduced. Many programs have been canceled and there are few new program starts anticipated. Two years ago there were two thermal battery producers in the U.S., but this decreased demand forced one to terminate its thermal battery production operations. Government agencies have studied and reviewed the sole source production situation and reviewed foreign thermal battery production capabilities, but in accordance with DOD's present acquisition policies, the U.S. military will continue to maintain the North American industrial base.

Two other companies, Martin Marietta and Westinghouse, recently have shown interest in thermal battery production operations, but the results of this interest are yet to be determined. To date, these companies have conducted R&D and demonstrated prototype production. Martin Marietta Specialty Components division has secured the Department of Energy's Pinellas Plant in Largo, Florida, intending to expand their thermal battery R&D and limited production efforts. This facility has seen limited thermal battery production in the past; therefore, Martin Marietta is not beginning these new operations with a large production capability. The Westinghouse Naval

Systems Group in Cleveland, Ohio also has recently demonstrated prototype thermal battery manufacturing capability. The company designed and produced a successful thermal R&D battery for the next generation of sonobuoys. Sandia National Laboratories also has limited thermal battery manufacturing capability.

These companies have not necessarily changed the immediate single-source supplier situation for military thermal batteries; rather, they have increased the R&D presence and limited production capabilities for prototype and commercial thermal batteries. The market is not expected to see any large growth in the near or far term, but the U.S. government has plans in place to maintain a North American capability. The market will remain static until additional military or new commercial applications arise that require increased manufacturing capability. At that point, these other companies may attempt to enter the regular production base for thermal batteries.

7.2.2 Lithium Batteries

Lithium primary batteries offer performance advantages well above the capabilities of conventional aqueous electrolyte battery systems. These batteries have the highest gravimetric energy (watt hours/kilogram), highest volumetric energy (watt hours/liter), and one of the best storage lives of any electrochemical battery system. These advantages are the main reason the military chooses lithium batteries for a variety of applications.

The lithium chemistries used by the military include primary lithium sulfur dioxide, lithium thionyl chloride, and lithium manganese dioxide. At present, the most widely used of these chemistries is lithium sulfur dioxide. North America currently has four major military lithium battery suppliers and a fifth with military production capability but no production demand.

7.2. Lithium Battery Marketplace Supply

Figure 7-2 lists the lithium battery companies and their products. The chart shows military battery sales for 1993 and military battery trends for 1994; and overall company sales for 1993 and trends for 1994. The total sales data may reflect only battery sales, or it may reflect the sum of battery and other products sales (e.g. - electronic chargers/analyzers, electronic devices). The sales data from suppliers did not delineate between revenues for different products. Following the chart is a brief overview of each company describing the company, its products, capabilities, and customers.

COMPANY INFORMATION			1993 COMPANY SALES			
Manufacturer Name	Parent/Owner Name	Battery Chemistry	Military Battery		Total Sales	
			M $	Trend	M $	Trend
Ballard Battery Systems	Ballard Power, Corp. Investors, Employees	LiSO2, LiMnO2	4.5	DOWN	4.5	DOWN
Battery Engineering Inc.	Hitachi (Maxell)	LiSOCl2	0.6	DOWN	3.4	UP
Power Conversion Inc.	British Tire and Rubber (BTR)	LiSO2, LiMnO2, LiSOCl2	8.4	DOWN	12	EVEN
SAFT America Inc. (Valdese)	Alcatel Alsthom - France	LiSO2	12.8	DOWN	20	DOWN
Yardney Technical Products	Self	LiSOCl2	0	0	3.0 lithium sales	EVEN

Figure 7-2. Companies in the Lithium Battery Market

7.2.2.1.1 Ballard Battery Systems Corporation

Ballard Battery Systems Corporation (BBSC) was established in North Vancouver, British Columbia in 1976 and is a subsidiary of Ballard Power Systems, Inc. Ballard was originally a research lab that performed developmental work on lithium batteries. In 1985 BBSC incorporated as BTC Engineering, Ltd. to commercialize primary lithium sulfur dioxide battery technology. BBSC has three segments of ownership: 50.3% Ballard Power Systems, 28.6% worldwide corporate investors, and 21.1% employees.

BBSC manufactures primary (non-rechargeable) lithium sulfur dioxide and lithium manganese dioxide cells and batteries. The lithium manganese dioxide cells and batteries are in very limited production.

Revenues were approximately $2.5 million in 1990, $7.5 million in 1991, $13 million in 1992 (due primarily to the Gulf War), and $4.5 to $5 million in 1993. Revenues in 1994 should remain the same as 1993. BBSC stated they require $4.5 to $5 million in yearly revenues to break even and that 1992 was the first year of real profits. BBSC has had over $20 million in sales of lithium sulfur dioxide military batteries since 1989.

In 1993, 90% of BBSC's revenue came from the U.S. government and 10% from Canada. In previous years this split was closer to 95% U.S. and 5% Canada. In 1994 the U.S. and Canada will combine for only 25% of BBSC's revenues; the remaining 75% will be from commercial and foreign customers.

7.2.2.1.2 Battery Engineering Inc.

Battery Engineering Inc. (BEI), located in Hyde Park, Massachusetts, is a small wholly owned subsidiary of Hitachi (Maxell), a Japanese company. BEI has been in existence approximately 17 years and was purchased by Hitachi on February 1, 1990. BEI is traded publicly on the New York Stock Exchange.

BEI manufactures low and moderate rate primary lithium thionyl chloride cells, in cylindrical, coin, prismatic, and other shapes; and batteries in a variety of configurations. In 1993 BEI claimed to have produced the smallest lithium thionyl chloride battery ever manufactured. The battery measured 0.397 inches long by 0.275 inches in diameter.

BEI's primary market is in the oil drilling industry. Sales in this industry accounted for 85% of BEI's $4 million in 1993. These batteries are used in the electronics of drill bits that perform geographic and chemical analyses.

BEI's military business constitutes 5% to 10% of total sales. Government customers include GSA and OEMs Hughes Aircraft, Teledyne (for the F16), and AMETEK (subcontracted through Yardney - engine monitoring computer backup battery). BEI also has some sales to the United Kingdom Ministry of Defense.

7.2.2.1.3 Power Conversion Inc.

Power Conversion, Inc. (PCI), located in Saddlebrook, New Jersey, is a wholly-owned subsidiary of British Tire and Rubber (BTR) of Great Britain. The company was started in 1970 solely to develop and apply lithium technology. PCI was purchased in 1986 by Hawker Siddeley and became part of the BTR conglomerate when BTR acquired Hawker Siddeley in 1991. BTR is a $15 billion diversified conglomerate which employs 180,000 people and has business interests in a wide range of industries.

PCI makes four lithium battery systems in both standard and custom sizes and shapes for industrial and defense applications. These systems are lithium sulfur dioxide, lithium thionyl chloride, lithium manganese dioxide, and lithium carbon monoflouride. Its annual sales in the battery market are approximately $12 million.

Seventy percent of PCI's business base is military-related. PCI has sold batteries to the military for the following applications:

test equipment	night vision equipment	global positioning systems
gas masks	data terminals	digital message devices
satellite radios	antennas	chemical agent monitors
memory back-up	navigation equipment	rescue radios/beacons
scramblers	radar	two-way radios (SINCGARS)
UHF radios	loudspeakers	

The U.S. Army has been PCI's main customer. When Operation Desert Shield/Storm was in full swing, there was a large demand for PCI's lithium batteries. However, when this operation ended, the need for these batteries greatly diminished, and the government either canceled contracts or tried to stretch them out. PCI was forced to close its Puerto Rico plant, which was dedicated to Army operations, in January 1993 due to lack of production orders.

PCI currently supplies the Navy with two types of batteries for the PRC 69 and the PRC 112 radios. PCI has supplied the Navy with lithium sulfur dioxide batteries for sonobuoys, but the Navy has not bought these particular sonobuoy batteries in five years due to the decreased defense posture. The company also supplies a lithium manganese dioxide battery for the CATSEYE night vision goggle system. PCI envisions they will no longer maintain large scale production capabilities for lithium sulfur dioxide batteries.

7.2.2.1.4 SAFT America Inc. (Valdese, NC)

SAFT (Societe des Accumulateurs Fixes et de Traction) America, Inc. is a leading manufacturer of primary (non-rechargeable) batteries such as lithium and secondary (rechargeable) batteries such as nickel cadmium. This company also manufactured thermal batteries for military customers but ceased these operations in 1993. SAFT America's direct parent, SAFT, is based in France and is a wholly owned subsidiary of Alcatel Alsthom, the fourth largest company in France. Alcatel is a French government owned conglomerate with world wide operations.

The original company was formed in the United States in 1959 by the Gulton Battery Company. They were the original inventor of rechargeable nickel cadmium batteries. Alcatel acquired SAFT in 1973 from Gulton. Alcatel maintains the standard of being number one or number two in the world in every venture they enter. SAFT claims it is number one worldwide in aviation batteries, industrial nickel cadmium batteries, torpedo batteries, and lithium batteries for defense applications. A sister company, with operations in the United States and Canada, is SAFT Nife, a wholly owned Swedish subsidiary of the parent SAFT company. Recently Gates Energy Products, located in Gainesville, Florida, sold their aerospace business to SAFT America. SAFT America also acquired the aerospace battery business of Johnson Controls.

SAFT America-Valdese manufactures lithium sulfur dioxide primary batteries. They are in the process of developing lithium ion secondary batteries. SAFT's military and commercial batteries are manufactured on the same production lines.

Of SAFT's lithium sulfur dioxide business, 64% is with the U.S. military, 31% is in export sales, and 5% is for the commercial market. The defense original equipment manufacturer (OEM) portion of SAFT's business is largely sonobuoy applications. Most of the export sales are for foreign military applications in the following countries: Israel, Germany, France, India, United Kingdom, Pakistan, Canada, Japan, and Scandinavian countries. Some of this business is through Foreign Military Sales (FMS). Last year Canada purchased nearly $1 million worth of BA-5590 batteries directly from SAFT. The commercial market uses SAFT's batteries for medical equipment (e.g. - defibrillators), animal tracking devices, and lighting equipment for the mining industry.

7.2.2.1.5 Yardney Technical Products Inc.

Yardney Technical Products is located in Pawcatuck, Connecticut. The company was founded in New York City in 1944 as Yardney Electric Corporation, and production moved to Pawcatuck, Connecticut in 1964. In 1969 a major interest was purchased by Whittaker Corporation, and the entire operation moved to Pawcatuck in 1970. Between 1971 and 1985, the Yardney Battery Division in Pawcatuck, Connecticut and the Power Sources Division in Denver, Colorado merged to create the Yardney Corporation. In 1990 Yardney Technical Products, Inc. was formed through a management buyout of Whittaker-Yardney Power Systems.

Yardney has a lithium battery manufacturing line for production of lithium sulfur dioxide BA5590 batteries for the Army, but its production facility has been sitting idle since its installation. The Gulf War promulgated emergency procurements for lithium sulfur dioxide batteries, and large orders were placed with SAFT and PCI. Yardney had signed a $70 million contract with the Army to produce the BA5590 battery for the Gulf War, but they failed to pass First Article and did not produce any military batteries. Yardney has yet to qualify for military lithium battery production, and the decreased demand for the BA5590 battery has not sparked urgent action by the military to qualify Yardney for this production.

Originally, Yardney was to produce the lithium sulfur dioxide batteries at the Whittaker-Yardney facility in Denver, Colorado. Yardney claims it took the Army two years to agree to move the production from Denver to Pawcatuck. To prepare the Pawcatuck site, Yardney obtained a loan from the state of Connecticut, made equipment purchases, and ramped up for full-scale production. At the end of the Gulf War, Yardney received some termination costs from the government but lost approximately $1 million of their own.

Yardney also manufactures primary lithium thionyl chloride batteries for the commercial market. These batteries are used in oil drilling electronics and computer memory backup devices. These commercial lithium sales constituted $3 million worth of sales in 1993 and accounted for approximately 20% of Yardney's 1993 business.

Yardney also produces primary and secondary silver zinc batteries, primary silver chloride magnesium batteries, and secondary silver cadmium batteries. Yardney has the capability to produce secondary nickel hydrogen cells and batteries but has not produced any in over a year. They have maintained this capability hoping for revived business but will soon start selling their idle equipment.

7.2.2.2 Lithium Battery Marketplace Demand

Figure 7-3 illustrates some typical military and commercial applications for lithium based batteries. All applications shown use either primary lithium sulfur dioxide, lithium thionyl chloride, or lithium manganese dioxide batteries, and in some instances, applications may use more than one form of lithium chemistry. Secondary (rechargeable) lithium manganese dioxide and lithium ion batteries are available in limited supply for portable computer and cellular telephone applications.

Typical Lithium Sulfur Dioxide Battery Applications	
Military	**Commercial**
global positioning systems	animal tracking devices
portable electronics	medical devices
sonobouys	portable computers
	portable lighting equipment

Typical Lithium Manganese Dioxide Battery Applications	
Military	**Commercial**
portable electronics	calculators
SINCGARS radio	cameras
	portable computers
	cellular telephones

Typical Lithium Thionyl Chloride Battery Applications	
Military	**Commercial**
mines	animal tracking devices
portable electronics	computer memory backup
	life support systems
	oil drilling electronics

Figure 7-3. Lithium Battery Applications

7.2.2.2.1 Military customers

The lithium marketplace has been driven primarily by military sales with some commercial/retail sales of lithium sulfur dioxide and lithium thionyl chloride batteries. The most common military lithium primary battery is lithium sulfur dioxide. The main military customer is the U.S. Army Communications and Electronics Command (CECOM). CECOM purchases lithium sulfur dioxide batteries for the Army and Marines in support of manportable (in the field) electronics. These electronics include night vision devices, global positioning systems, chemical agent detection and monitoring devices, walkie talkies, and portable computers.

After completion of three contracts (one each with Ballard Battery Systems, PCI, and SAFT America), CECOM will not purchase any more lithium sulfur dioxide batteries. These three contracts and surplus from the Gulf War will satisfy CECOM's requirements for the next three to five years. At that time, CECOM intends to purchase batteries utilizing the next generation of lithium chemistry or some other replacement chemistry.

The contract signed in 1990 with Ballard Battery Systems was designed to be a five year contract. CECOM, primarily due to the Gulf War, accelerated delivery under the contract, and Ballard plans to supply CECOM with lithium sulfur dioxide BA5600 batteries only through the end of 1994.

In the beginning of 1994 two one year contracts were signed with PCI and SAFT America for six different configurations of lithium sulfur dioxide batteries. Four of these batteries were contracted as contingency batteries (for the possibility of newly developed/implemented systems) but probably will never be produced. The main battery supplied by both manufacturers is the lithium sulfur dioxide BA5586 batteries for the PRC126 radio.

If CECOM finds that another lithium chemistry is more cost effective than the lithium sulfur dioxide battery and supplies the required performance characteristics, the lithium sulfur dioxide system may disappear from the battery market. Manufacturers are aware of this situation and realize that when present contracts end, there will likely be no major military demand for lithium sulfur dioxide batteries. This downsizing has already left three manufacturers with excess manufacturing capacity, and a fourth manufacturer has a complete lithium sulfur dioxide production line for military batteries that never produced a single production run for the military.

The Navy has been satisfied with the lithium manganese dioxide battery systems for their applications and will continue using them because of their increased safety over lithium sulfur dioxide batteries. The Navy also will consider the lithium thionyl chloride chemistry for use in mines; they will introduce these new mines in the 1995 time frame.

7.2.2.2.2 Commercial customers

The commercial market uses lithium thionyl chloride, lithium sulfur dioxide, and lithium manganese dioxide batteries in a small number of applications. Commercial applications of primary lithium thionyl chloride batteries include animal tracking devices, oil drilling electronics, timing devices, and life support systems. Commercial applications of primary lithium manganese

dioxide batteries include watches, calculators, and cameras. Commercial applications of lithium sulfur dioxide batteries include medical devices, animal tracking devices, and lighting on mining helmets.

Figure 7-4 depicts North American military, foreign military, and commercial lithium battery sales figures from the five military lithium battery suppliers. Other commercial suppliers of lithium batteries include Duracell, Eveready, and other foreign companies. Commercial sales of lithium batteries are small in comparison to military sales. Of the four military lithium battery producers, total military sales in 1993 were approximately $26.3 million. All five manufacturers combined for $38.4 million in total lithium battery sales in 1993 with approximately $6 million in foreign military lithium sales and $6.1 million in commercial lithium battery sales.

LITHIUM BATTERY SALES FOR 1993				
	North American Military	**Foreign Military**	**Commercial**	**Total**
Dollars in millions	26.3	6	6.1	38.4
Percent of Total Sales	68.5	15.6	15.9	100

Figure 7-4. Lithium Battery Sales

7.2.2.3 Lithium Battery Marketplace Trends

The present market for lithium batteries represents a small fraction of the overall battery market, and they are not as popular in the commercial marketplace as alkaline or nickel cadmium batteries. However, in today's market, primary lithium batteries are available, and secondary lithium ion and lithium manganese dioxide batteries are available commercially for laptop computers and cellular telephones. Lithium battery technology has had a greater demand in military applications. A large part of the military's primary battery budget was for lithium batteries, mainly lithium sulfur dioxide batteries.

The domestic demand for lithium batteries will grow steadily [illegible] expected to reach $10 million for lithium rechargeable batteries and $120 million for lithium primary batteries by the year 2000. This increase will be driven by the development and consumer demand for portable, battery operated electronics and devices. Today much of this demand is filled by nickel cadmium batteries; in the future it may be filled by nickel metal hydride batteries due to their higher energy density

than nickel cadmium batteries. The consumer demand for longer service time presents an opportunity for secondary lithium batteries. The large scale introduction of these batteries into the commercial market will be slow until the cycle life, rate capability, reliability, safety, and competitive cost (to other chemistries) have been demonstrated.

Commercially, Duracell has limited the available configurations of their lithium manganese dioxide batteries for cameras. This has prompted these electronics manufacturers to design their products around the Duracell batteries. This standardization should soon find its place in the portable computer battery market as well and should affect the future of lithium batteries.

The decision by CECOM to suspend lithium sulfur dioxide procurements has dramatically changed the face of the marketplace. The cost of lithium sulfur dioxide batteries has prompted CECOM to complete its present contracts and study the cost effectiveness of other battery systems until the need for more batteries arises. CECOM will consider lithium ion or lithium manganese dioxide batteries as a potential replacement for lithium sulfur dioxide batteries. If these other chemistries mature into successful products and satisfy the performance specifications, CECOM will likely procure lithium battery configurations other than the lithium sulfur dioxide system. CECOM cannot be sure if any lithium sulfur dioxide manufacturers will remain, but feels that someone may retain, or be willing to resurrect, the capability. SAFT America-Valdese almost closed their lithium facility after the Gulf War but are now maintaining limited production for the military and are attempting to transition into the commercial lithium marketplace. Ballard depends solely on sales to the U.S. and Canadian governments and is also attempting to transition into commercial products. Yardney has no military lithium battery sales. PCI will continue to rely on government sales. PCI hopes for future increased military lithium sales through their lithium manganese dioxide pouch battery.

Safety has had and will continue to have a large impact on the lithium battery marketplace. Lithium is a highly reactive metal with air or water, and the electrolytes, sulfur dioxide and thionyl chloride, are toxic gases. Unfavorable conditions or mishandling of these batteries can incur undesirable chemical reactions, causing the battery to rupture and allowing toxic materials and toxic gases to escape. These safety concerns have caused the Federal Aviation Administration (FAA) to prohibit certain lithium sulfur dioxide and lithium thionyl chloride batteries within the confines of the breathing space on airplanes.

The lack of military demand has prompted some manufacturers to pursue other lithium chemistries and enter deeper into the commercial market. The transition into the commercial

marketplace for these military manufacturers will not be immediate or easy; moreover, the commercial demand for lithium batteries must increase in order to present a viable commercial base.

7.2.3 Mercury Batteries

Mercury batteries are not a high demand battery chemistry and very few companies offer production of this chemical system. This section discusses the only North American company; Gold Peak, located in China, is the only other manufacturer.

7.2.3.1 Mercury Battery Marketplace Supply

Figure 7-5 illustrates the only domestic producer of mercury batteries. The chart shows military battery sales for 1993 and military battery trends for 1994; and overall company sales for 1993 and trends for 1994. The total sales data may reflect only battery sales, or it may reflect the sum of battery and other products sales (e.g. - electronic chargers/analyzers, electronic devices). The sales data from suppliers did not delineate between revenues for different products. Following the chart is a brief overview describing the company, its products, capabilities, and customers.

COMPANY INFORMATION			1993 COMPANY SALES			
Manufacturer Name	Parent/Owner Name	Battery Chemistry	Military Battery		Total Sales	
			M $	Trend	M $	Trend
Alexander Batteries Inc.	Family owned	Mercury	0.423	UP for 1994 BEYOND 1994 DOWN	29	UP

Figure 7-5. Companies in the Mercury Battery Market

7.2.3.1.1 Alexander Batteries

Alexander Batteries, located in Mason City, Iowa, is a family owned business with approximately 400 employees. Alexander Batteries is the only domestic producer of mercury cells and only world producer of cylindrical mercury cells. The company produces batteries for medical equipment, cellular telephones, and portable electronic devices. The medical equipment is mostly portable monitor equipment, and the company supplies replacement batteries for different types of

electronic devices. Approximately 10% of Alexander Batteries' total business is with the government (including GSA).

The company primarily repackages pre-purchased cells but also manufactures mercury cells. Alexander Batteries began manufacturing mercury cells in 1983. Prior to 1983, the company purchased mercury cells from Duracell and packaged the final product, but increasing cell costs prompted Alexander to manufacture the cells in house. The mercury cells are available in limited sizes.

The company stated that 80% of their mercury battery production is for the U.S. military. Most of the commercial market is supplied with olt cells; these are used for portable medical monitors in hospitals. Alexander Batteries did not provide any other specific sales information.

7.2.3.2 Mercury Battery Marketplace Demand

Figure 7-6 illustrates some typical military and commercial applications for mercury primary batteries.

Typical Mercury Battery Applications	
Military	**Commercial**
communications devices	portable electronics
mines	portable medical devices
munitions	
portable electronics	
surveillance systems	

Figure 7-6. Mercury Battery Applications

7.2.3.2.1 Military customers

The mercury market is driven almost totally by the military. There is only one North American manufacturer of mercury batteries, and 80% of the company's mercury battery production is for military systems. The military uses the mercury batteries primarily to support legacy systems from the 1960's and early 1970's. As these legacy systems are replaced, new

systems will utilize other chemistries. The Navy uses mercury batteries in mines and, because they have long shelf lives, they will be around for a while. However, when the Navy replaces these systems, the demand for mercury batteries will decrease. Demand in early 1994 from all four Service branches has increased from 1993 in support of legacy radio systems and Navy mines, but this is an anomaly; future demand will decrease.

7.2.3.2.2 Commercial customers

Primary commercial use of mercury batteries is for medical portable electronics such as heart monitors. Due to the safety concerns of mercury, thirteen states have banned the commercial sale of mercury batteries, and it is likely that more will follow. Some states, such as New Jersey and Minnesota, presently offer exemptions to the mercury battery ban only for batteries supporting medical equipment.

7.2.3.3 Mercury Battery Marketplace Trends

CECOM and others are trying to move away from mercury batteries, primarily due to environmental concerns. Presently, CECOM is purchasing mercury batteries to support legacy systems, but as these systems are replaced, the military will discontinue procurements of the mercury battery chemistry.

The military has provided Alexander Batteries with 80% of its business. With the military phase out of mercury batteries, this company will probably discontinue mercury battery manufacturing. The military, considering the environmental impact of mercury and the advances in other battery chemistries, does not see the loss of the mercury battery chemistry as a major concern.

7.2.4 Silver Zinc / Silver Cadmium Batteries

Silver zinc batteries can be either primary, primary reserve, or secondary while silver cadmium batteries are a secondary battery. The military uses these batteries primarily on missiles, torpedoes, and underwater vehicles. The commercial market for both chemistries is small; however, primary silver zinc batteries are commonly used for small portable electronics.

7.2.4.1 Silver Battery Marketplace Supply

Figure 7-7 illustrates various companies and their products. The chart shows military battery sales for 1993 and military battery trends for 1994; and overall company sales for 1993 and trends for 1994. The total sales data may reflect only battery sales, or it may reflect the sum of battery and other products sales (e.g. - electronic chargers/analyzers, electronic devices). The sales data from suppliers did not delineate between revenues for different products. Following the chart is a brief overview of each company describing the company, its products, capabilities, and customers.

COMPANY INFORMATION			1993 COMPANY SALES			
Manufacturer Name	Parent/Owner Name	Battery Chemistry	Military Battery		Total Sales	
			M $	Trend	M $	Trend
BST Systems	privately owned	silver zinc, silver cadmium	Not Disclosed	DOWN	Not Disclosed	DOWN
Eagle-Picher, Joplin, Missouri	Eagle-Picher Industries, Inc.	silver zinc, silver cadmium	Not Disclosed	EVEN	Not Disclosed	EVEN
Whittaker Power Storage Systems	Whittaker	silver zinc	8	DOWN	8	DOWN
Yardney Technical Products	self	silver zinc, silver cadmium	9.6	DOWN	14	EVEN

Figure 7-7. Companies in the Silver Battery Market

7.2.4.1.1 BST Systems, Inc.

BST Systems is located in Plainfield, Connecticut and has been in business for approximately eleven years. The company manufactures battery cells and assembles the final battery products on a three shift rotation. BST batteries are sold mostly to military and government customers, but the company also has sales to some commercial customers. During the last eleven years, BST has expanded their assembly facility and installed and updated automated equipment to meet the production demands of their customers.

BST manufactures a variety of primary and secondary silver zinc batteries and has the capability to manufacture silver cadmium batteries. In 1993 military sales accounted for

approximately 80% of BST's total sales with 20% commercial sales. The Navy uses these batteries on many different training equipment systems and armament systems such as deep sea rescue vehicles, deep submergence vehicles, submarines, target drones, and missiles. Aerospace companies use BST batteries in the Space Shuttle and the Delta rocket system. The most common commercial silver battery which BST manufactures is used in electronic news gathering equipment devices.

BST currently does not have any demand for their silver cadmium batteries, but they continue to offer the capability to interested customers. The company does not sell any of their products to the Canadian government or military, but they have sold products to countries overseas.

7.2.4.1.2 Eagle-Picher Industries (EPI)

See section 7.2.1.1 for additional information.

The Eagle-Picher facility in Joplin, Missouri manufactures thermal, silver zinc, and silver cadmium batteries for mostly military customers. EPI supplies silver batteries to Navy customers for various applications including missiles, torpedoes, and underwater vehicle propulsion systems.

Eagle-Picher is a major supplier of primary and primary reserve silver zinc batteries to the military. Their batteries are used in many different missile systems. Yardney, Whittaker, and Eagle-Picher all have been suppliers of the primary reserve silver zinc batteries to the Navy, but with the military downsizing, Eagle-Picher may become the sole supplier for naval applications. Yardney's production contracts for these batteries ended in FY93, and Whittaker does not have a strong foothold with the Navy. In particular, both Yardney and Eagle-Picher build the D5 battery for Navy systems, but beginning in FY94 all contracts for these batteries will be with EPI.

7.2.4.1.3 Whittaker Power Storage Systems

Whittaker Power Storage Systems (WPSS) is located in Denver, Colorado and is a division of publicly held parent company Whittaker. The parent Whittaker facility is located in the Los Angeles, California area. Whittaker has two other divisions in California: Electronic Systems located in Simi Valley, and the Controls Division also located in the Los Angeles area.

WPSS handles all battery cell manufacturing, battery assembly, and testing operations in their own facility and employs approximately 50 people for these operations. The company sells their batteries almost exclusively to military and government customers and has supplied foreign customers in the past. WPSS manufactures and assembles primary and primary reserve silver zinc battery systems. The batteries are used mostly in missile systems.

In 1993 WPSS had approximately $8 million dollars in sales. Recent military cutbacks have affected Whittaker. WPSS currently has production capacity of approximately 3000 units per year but is not running at full capacity in 1994.

7.2.4.1.4 Yardney Technical Products Inc.

See section 7.2.2.1.5 for additional information.

Yardney produces primary, primary reserve, and secondary silver zinc batteries and secondary silver cadmium batteries. The U.S. military is Yardney's main customer. Total sales of silver zinc and silver cadmium batteries were $12 million in 1993 of which military sales accounted for approximately $9.6 million. Yardney has the capability to produce secondary nickel hydrogen cells and batteries but has not produced any in over a year. They have maintained this capability hoping for revived business but will soon start selling their equipment if they continue to not receive steady orders for the battery.

The silver cadmium batteries produced by Yardney support only one U.S. military application, the MK 48 torpedo. These silver cadmium battery sales in 1993 were approximately $250,000. Yardney will complete their existing silver cadmium contract at the end of 1994. Since the Navy uses the MK 48 torpedo for training exercises, there will most likely be continued, although limited, demand for the silver cadmium battery. Yardney also manufactures non-magnetic silver cadmium batteries used in satellites for an Italian Aerospace company. This equates to approximately $100,000 worth of yearly business. Silver cadmium batteries are manufactured essentially on the same production line as the silver zinc batteries except for separate handling of the cadmium.

Yardney does have a dedicated Battery Control Line (BCL) for production of the Navy D5 silver zinc battery that is used for the Trident II missile system. Previously, Yardney manufactured the C3 Poseidon and C4 Trident silver zinc missile system batteries on their regular production lines, but Lockheed (the prime contractor) wanted a dedicated line for the D4 and D5 Trident

battery. Yardney does not have additional orders for this D5 silver zinc battery, and the production line is idle. The Navy owns all of the equipment for this production line, and Yardney is waiting for Lockheed to instruct them what to do with the equipment. Lockheed will either remove it or use it for other production within the Yardney facility.

7.2.4.2 Silver Battery Marketplace Demand

Figure 7-8 illustrates some typical military and commercial applications for primary and secondary silver zinc batteries and secondary silver cadmium batteries.

Typical Primary Silver Zinc Battery Applications	
Military	**Commercial**
missiles (primary reserve)	watches
torpedoes	calculators
unmanned undersea vehicles	hearing aids

Typical Secondary Silver Zinc Battery Applications	
Military	**Commercial**
SEALS delivery vehicle	electronic news gathering
missiles	televison cameras
torpedoes	

Typical Silver Cadmium Battery Applications	
Military	**Commercial**
torpedoes	portable power tools
satelites	

Figure 7-8. Silver Battery Applications

7.2.4.2.1 Military customers

The most widely used batteries in the silver chemistry are silver zinc primary, primary reserve, and secondary batteries. The military uses primary reserve silver zinc batteries mostly on missiles and secondary silver zinc batteries on torpedoes and underwater propulsion. The silver zinc batteries used by the military are quite different from the small, single cell batteries used in

commercial electronic devices. The market for silver zinc batteries has two general facets: the single cell batteries for small electronic devices and the multi-cell batteries for military applications.

7.2.4.2.2 Commercial customers

The commercial market for the silver chemistry configurations is small. Primary silver zinc batteries are commonly used for small portable electronics such as calculators, watches, and hearing aids; secondary silver zinc batteries are used in news gathering equipment. The multi-cell industrial silver zinc batteries used in the news gathering equipment constitute only a few percent of the overall silver zinc battery usage. Secondary silver zinc batteries offer a lot of power but are not truly practical in the commercial market. They are somewhat expensive and usually only give 60 to 100 cycles.

7.2.4.3 Silver Battery Marketplace Trends

Silver zinc primary batteries likely will continue to serve niche markets where the cost of the battery is acceptable relative to the application. In particular, primary reserve silver zinc batteries will continue to be used in missiles for the military, and silver zinc primary batteries will continue to be used in advanced medical devices. The small, single cell batteries used for calculators and wristwatches will remain a stable market. These batteries offer good power, long cycle life, and acceptable cost. They are mass produced for the commercial market, but the military market has yet to implement them into their applications.

Silver zinc secondary batteries, even though they offer good power, have relatively short cycle life. They are used in a small number of commercial applications and most likely will remain a military battery.

The future of the silver battery industry will be dictated primarily by the military and aerospace markets. For silver zinc primary batteries, annual U.S. sales are expected to grow from $15 million in 1992 to approximately $18 to $20 million in 2000. Secondary silver zinc battery annual U.S. sales are expected to grow from $32 million in 1992 to approximately $60 to $80 million in 2000. Silver zinc battery usage within the military may increase in the near future with improved silver zinc batteries; research is ongoing to improve the properties and cycle life of these batteries. NASA should continue to be a large customer of silver zinc batteries; Eagle-Picher Industries claims that every manned space flight from Mercury through Gemini, Apollo and now

the Space Shuttle have used their silver zinc batteries. One of the major drawbacks of silver zinc batteries is their cost.

Silver cadmium batteries are very expensive but satisfy a niche market. With environmental concerns over cadmium, limited applications, decreasing defense dollars, and improvements in other chemistries, the silver cadmium electrochemical system faces an unclear future market demand.

Silver cadmium secondary batteries are used in military torpedoes and commercially for portable power tools and satellites. All of these markets are very small. Silver cadmium is an expensive system with limited applications and an environmentally unfriendly component (cadmium). This battery system will experience little future growth and will continue to satisfy small niche applications. Growth for silver cadmium batteries is projected to increase slightly from 1992 sales of $1.5 million to $2 to $2.5 million in 2000.

7.2.5 Lead Acid Batteries

Lead acid battery technology has been in use for over 100 years. Lead acid batteries are the most widely used secondary (rechargeable) batteries in the world. Applications span the range from small portable electronics to large military systems. The popularity of lead acid batteries is attributed to the maturity of the technology, the low cost of materials, the widespread recycling of lead, and a relatively wide temperature range for cycling and non-cycling applications.

This section deals only with lead acid systems since they are the most common in the family, but another niche lead battery chemistry is the lead lead dioxide primary reserve system. This battery is used by the Army and Navy for projectile fuses and is produced by a sole manufacturer, Acudyne.

7.2.5.1 Lead Acid Battery Marketplace Supply

Figure 7-9 illustrates lead acid battery manufacturers and their products. These four suppliers are not the only lead acid battery suppliers throughout North America; rather, they are the suppliers that were identified for this report as dealing within the military/government environment. Other suppliers exist that satisfy commercial demand. The chart shows military battery sales for 1993, military battery trends for 1994, and overall company sales for 1993 and trends for 1994. The total sales data may reflect only battery sales, or it may reflect the sum of

battery and other products sales (e.g. - electronic chargers/analyzers, electronic devices). The sales data from suppliers did not delineate between revenues for different products. Following the chart is a brief overview describing each company, its products, capabilities, and customers.

Company Information			1993 Company Sales			
Manufacturer Name	Parent/Owner Name	Battery Chemistry	Military Battery		Total Sales	
			M $	Trend	M $	Trend
Concorde Battery Corp.	Privately owned	Lead Acid	2.352	EVEN	12	UP
C&D Charter Power Systems Inc.	Charter Power Systems Inc.	Lead Acid	2	UP	163	UP
GNB Battery Technologies Inc.	Pacific Dunlop Ltd. - Melbourne, Australia	Lead Acid	10	UP	779	UP
Johnson Controls Battery Group	Johnson Controls	Lead Acid	0	NONE	700	UP

Figure 7-9. Companies in the Lead Acid Battery Market

7.2.5.1.1 Concorde Battery Corporation

Concorde is a small, privately held company which started in 1977 making plates for batteries. In 1980 Concorde made their first lead acid batteries for aircraft applications. The owners of Concorde own another company named Interspace Battery, Inc.; it is located in the same facility as Concorde. Interspace makes plates for batteries which are sold in and outside of the United States, one identified customer being Mexico.

Concorde has an equal split in sales between military and commercial markets, with 75% of all sealed lead acid battery sales to the military. Concorde produces lead acid batteries for wheelchairs, commercial marine, commercial general aviation aircraft (corporate and private airplanes - not commercial jetliners), and military aircraft.

Concorde's primary military customers are the Navy and Air Force. Concorde is working with the Air Force on a retrofit program for the KC135 aircraft; this will include the replacement of nickel cadmium batteries with sealed lead acid batteries. Concorde also has qualified batteries for the Air Force and the Navy to use on the C130 and P-3 aircraft. Canada and the U.S. Navy use

Concorde batteries on their F18 aircraft. This battery also is used in the H-46 helicopter, F-117 Stealth, and the AV-8B.

7.2.5.1.2 C & D Charter Power Systems, Inc.

C&D Charter Power Systems, Inc. (C&D) is a wholly-owned subsidiary of Charter Power Systems, Inc. Charter Power Systems is a publicly traded corporation on the American Stock Exchange. In 1992, C&D was reorganized into three business units: the Standby Power unit, the Motive Power unit, and the Power Electronics unit. In that same year, C&D completed the acquisition of Ratelco, Inc., a Seattle, Washington-based producer of direct-current power equipment for the communications industry. This acquisition expanded their industrial battery market.

C&D makes lead acid batteries and battery power systems for commercial, industrial, and government stand-by power systems (including uninterruptible power supplies) and automotive markets.

C&D's 1993 annual sales were $163 million, of which $2 million were from sales to the government. Of that $2 million, $1.8 million were for batteries for the Trident submarine and approximately $200K were for the Minuteman missile system. The Trident contract is scheduled to end in the summer of 1994, but C&D will maintain this production capability. The only other manufacturer of the Trident submarine battery is GNB Battery Technologies.

C&D is the single source producer of the Minuteman Missile silo batteries and has a contract scheduled to end in June of 1994. However, this contract has been extended, and the volume has been increased twelve fold. C&D considers these batteries easy to make and similar to their motive power battery.

7.2.5.1.3 GNB Battery Technologies Inc.

GNB (Gould National Battery) Battery Technologies Inc. is owned by Pacific Dunlop GNB Holdings Inc. in Chicago, Illinois, which in turn is owned by Pacific Dunlop Limited in Melbourne, Australia. GNB markets automotive and industrial batteries in over 50 countries and has 24 manufacturing plants (20 in North America).

GNB is the third largest battery manufacturer in the world, the second largest lead acid battery recycler in the world, and the largest battery manufacturer in North America. GNB manufactures flooded and valve regulated (sealed) lead acid batteries. GNB had $779 million in sales in 1993 and does $6 to $10 million of business annually in submarine batteries.

GNB's main military customer is the U.S. Navy. GNB batteries are on 27 Navy Spruance ships and in Sea Wolf submarines. GNB also supplies batteries to the U.S. Air Force for missile silo backup and has approximately $6.5 million worth of batteries in missile silos.

7.2.5.1.4 Johnson Controls

Johnson Controls (JC) is composed of four business groups: Control Group, Auto Seating Group (ASG), Plastics Group, and Battery Group (BG). The Control Group has 330 branches worldwide and is involved in facilities management (e.g. - Cape Canaveral and Indiana Hoosier Dome). The ASG manufactures automotive seats for a variety of auto manufacturers; the Plastics Group produces a variety of plastic containers; and the Battery Group produces automotive batteries.

The JC-BG manufactures lead acid batteries, and their specialty batteries division, Globe Union, manufactures gel, wet, and absorbed glass mat (AGM) lead acid batteries and nickel metal hydride batteries. JC has a program with W.R. Grace in Maryland to produce lithium polymer batteries. JC-BG has battery manufacturing facilities throughout the United States. The specialty batteries division employs 300 people and has a production capacity of one million batteries per year.

The JC-BG produces one out of every three automotive batteries sold in the United States under the brand names of Sears Die Hard, Interstate, Ford Motor, Wal Mart, Energizer, and Eveready. Last year the battery group had $700 million in sales. Globe Union was bought by JC-BG in 1978, and accounted for $50 million of the $700 million battery revenues. JC sells 85% of its batteries to the automotive aftermarket. The battery shipments increased 4.5% for JC in 1993, but sales revenues decreased slightly due to lower battery selling prices. These lower selling prices were caused in part by decreased cost of raw materials.

JC-BG supplies these aftermarket, replacement batteries to almost all of the major automotive makers in North America, Asia, Europe, and Australia. JC-BG is not aware of any battery sales to the government or military, but it is likely that the government and military

purchase some number of JC batteries through distributors or retailers not associated with JC. JC-BG has sold batteries to the Canadian Department of Defense and Canadian nuclear power plants for backup power supply systems. The specialty division has sold custom batteries to both Lockheed and Motorola which cost upwards of $500,000 each.

7.2.5.2 Lead Acid Battery Marketplace Demand

Figure 7-10 illustrates some typical military and commercial applications for lead acid batteries. All lead acid batteries discussed here are secondary batteries.

Typical Lead Acid Battery Applications	
Military	**Commercial**
aircraft engine starting	aircraft engine starting
silo backup	automotive
submarine propulsion	camcorders
utility vehicles	portable computers

Figure 7-10. Lead Acid Battery Applications

7.2.5.2.1 Military customers

The military uses lead acid batteries primarily for vehicle starting, lighting and ignition, aircraft engine starting, aircraft ground equipment, motive power on submarines, and standby power systems in missile silos. The manufacture of lead acid batteries does not vary greatly except for configuration. Submarine lead acid batteries are much larger than an automotive lead acid battery.

7.2.5.2.2 Commercial customers

Although there are lead acid batteries for such things as portable computers and communications devices, the lead acid market is almost totally driven by automotive and standby power applications. This has kept the lead acid market stable and growing slowly. The largest market for lead acid batteries is in the automotive aftermarket (replacement batteries).

7.2.5.3 Lead Acid Battery Marketplace Trends

Lead acid batteries are one of the most probable candidates for use in electric vehicles in the near term. Their biggest impediment is their weight.

For certain aviation systems, sealed lead acid batteries are replacing vented nickel cadmium batteries, but more commonly, only the older, vented lead acid batteries are being replaced with valve-regulated, sealed lead acid batteries. The sealed batteries require little or no maintenance. In particular, the KC-135 will be retrofitted with the valve-regulated, sealed lead acid battery in 1995 to replace the vented nickel cadmium battery. The sealed lead acid battery is expected to have a service life from 2 to 3 years.

The major problem that the aviation market faces with the lead acid batteries is their limited operating temperature range, but recently the batteries have been installed with heaters to maintain a satisfactory operating temperature.

With an established commercial base and market, the lead acid battery industry is expected to continue strong growth into the year 2000. U.S. sales of lead acid motive power batteries are expected to increase from $310 million in 1992 to $400 million in 2000; standby power system batteries from $280 million in 1992 to $415 million in 2000; consumer lead acid batteries from $160 million in 1992 to $300 million in 2000; and automotive lead acid battery sales from $2,350 million in 1992 to $3,000 million in 2000.

Increased use of lead acid batteries in aircraft, the emergence of the electric vehicle, the proven manufacturing processes, the use of recycled lead, and the continued demand in the automotive aftermarket will keep the lead acid battery market strong for many years.

7.2.6 Nickel Cadmium Batteries

Nickel cadmium is the most widely used nickel chemistry by the military. Nickel cadmium batteries have a rugged construction and proven reliability. Characteristics like high power capabilities, a wide operating temperature range, and long cycle life make them suitable for many applications. In smaller sizes they may be sealed, eliminating water addition maintenance. Presently North America has three major military nickel cadmium battery suppliers. These manufacturers produce military and commercial aviation batteries which are quite different from the commercial cells sold in the retail market to support portable consumer electronics.

7.2.6.1 Nickel Cadmium Marketplace Supply

Figure 7-11 illustrates various companies and their products. The chart shows military battery sales for 1993 and military battery trends for 1994; and overall company sales for 1993 and trends for 1994. The total sales data may reflect only battery sales, or it may reflect the sum of battery and other products sales (e.g. - electronic chargers/analyzers, electronic devices). The sales data from suppliers did not delineate between revenues for different products. Following the chart is a brief overview of each company describing the company, its products, capabilities, and customers.

Company Information			1993 Company Sales			
Manufacturer Name	Parent/Owner Name	Battery Chemistry	Military Battery		Total Sales	
			M $	Trend	M $	Trend
Eagle-Picher, Colorado Springs, CO	Eagle-Picher Industries, Inc.	nickel cadmium	Not Disclosed	EVEN	Not Disclosed	EVEN
Marathon Power Technologies	Penn Central	nickel cadmium	2.6	EVEN	17	EVEN
SAFT America (Valdosta)	Alcatel Alsthom - France	nickel cadmium	6	UP	19	DOWN

Figure 7-11. Companies in the Nickel Cadmium Battery Market

7.2.6.1.1 Eagle-Picher Industries Inc.

See sections 7.2.1.1 and 7.2.4.1.2 for additional information.

EPI's Colorado Springs facility produces nickel cadmium and nickel hydrogen (a cross between a battery and a fuel cell) batteries. Sales of these batteries have been historically stable with an equal split of sales between aerospace vehicles and aircraft. Of EPI's total dollar revenue, 10% has come from the production of specialty batteries.

Aerospace batteries, both nickel cadmium and nickel hydrogen, are sold to NASA and Hughes for use in satellites. Aircraft battery sales are all nickel cadmium. Of the 50% sales for

aircraft, 40% to 45% are for civilian aircraft (primarily helicopters) and 5% to 10% are for military aircraft.

7.1.6.1.2 Marathon Power Technologies

Marathon Power Technologies is located in Waco, Texas. The company began operations in 1970 and is owned by Penn Central; however, the company may be sold in the near future, and the buyer will not be disclosed until after the sale. Marathon manufactures and repackages nickel cadmium sealed and vented cells, primarily for aviation.

Approximately 17% of Marathon's business is with the U.S. government. Total sales for Marathon are approximately $17 to $18 million per year. Marathon has the capability for much higher government sales as evidenced in 1988 when SAFT had been disbarred by the government for seven months, and Marathon's government sales rose to 50% of total sales.

7.2.6.1.3 SAFT America Inc. (Valdosta, GA)

See section 7.2.2.1.4 for additional information.

SAFT's Industrial Battery Division is located in Valdosta, Georgia. The company produces nickel cadmium batteries at the Valdosta plant for aviation, industrial use, and electric vehicles. The aviation batteries are used mostly for civil and military fixed and rotary wing aircraft, and the industrial batteries are used mostly for rail transit systems and standby power. All of SAFT's military nickel cadmium batteries are built in Valdosta. Some of the individual cells may be produced outside the U.S. (Mexico and France), but over 51% of the total cost of the battery occurs in the U.S. SAFT produces military and commercial batteries on the same assembly line. The company does not produce any nickel cadmium batteries in the U.S. for portable electronic devices.

SAFT America-Valdosta had $19 million in sales in 1993. Six million dollars of that revenue was from military customers, which accounted for 50% of SAFT's production volume. In 1993 Army sales totaled $2.3 to $2.4 million, Navy sales totaled $500,000, Air Force sales totaled $2 million, and foreign military sales through brokerage totaled $500,000 ($68,000 sold directly to foreign embassies).

7.2.6.2 Nickel Cadmium Battery Marketplace Demand

Figure 7-12 illustrates some typical military and commercial applications for nickel cadmium batteries. The demand discussed in this section deals primarily with nickel cadmium batteries for aviation and aerospace.

Typical Nickel Cadmium Battery Applications	
Military	**Commercial**
electronic devices	commercial aircraft
military aircraft	portable electronics
orbitting spacecraft	small A/C engine starting
utility vehicles	solar energy storage
	standby power

Figure 7-12. Nickel Cadmium Battery Applications

7.2.6.2.1 Military customers

The military uses nickel cadmium batteries mostly for aircraft and aerospace equipment. These batteries are capable of providing high power levels at cold temperatures. McDonnell Douglas uses sealed nickel cadmium batteries on its MD-80 and DC-9 aircraft, and Boeing expects to use them on the 777 aircraft.

The advantages of sealed nickel cadmium batteries are lower maintenance costs and easier storage. These advantages make worldwide deployment easier, and the batteries require maintenance only once every 4 years. Vented nickel cadmium batteries require maintenance every 28 to 180 days. The Air Force is expected to retrofit some B-52 aircraft with sealed nickel cadmium batteries during FY 94.

Some battery manufacturers are working with the Navy to field a series of very low maintenance, vented nickel cadmium batteries that may require maintenance only once per year. The advantage of the ultra-low maintenance battery over the sealed nickel cadmium batteries is that current applications that use nickel cadmium systems do not need to be altered in order to install the new, low maintenance system. Therefore, significant savings in maintenance operations will be realized without a significant initial implementation cost.

7.1.6.2.2 Commercial customers

The commercial market for nickel cadmium batteries is driven primarily by portable electronics and commercial aviation sales. The small single cell batteries that populate the commercial portable electronics marketplace have not found their way into military use; these nickel cadmium batteries do not last as long as other batteries, require additional logistics support for charging, and in some cases cost more than other batteries already being used. Lithium sulfur dioxide batteries are commonly used for commercial applications that require longer cycle lives than the nickel cadmium batteries.

7.2.6.3 Nickel Cadmium Battery Marketplace Trends

For general aviation and consumer electronics the nickel cadmium market is fairly stable. Some manufacturers have stated that general/commercial aviation nickel cadmium batteries are better quality (mostly in components, but also in some manufacturing processes) than the batteries purchased by some branches of the military.

The military nickel cadmium market is also stable. Presently the Air Force is pursuing increased use of maintenance-free sealed nickel cadmium batteries to replace the vented nickel cadmium batteries and some vented lead acid systems. Although the nickel cadmium batteries cost more than lead acid batteries, the Air Force can save approximately $3000 in annual battery maintenance costs per aircraft when compared to existing vented nickel cadmium systems. The Navy is also attempting to implement an ultra-low maintenance, vented nickel cadmium system that can decrease maintenance costs and does not require modifications to the applications. For the longer term future, the Air Force is working with one nickel cadmium battery manufacturer to develop a battery that will last twenty years of active service.

Future demand of sealed nickel cadmium batteries is projected to increase from $440 million in 1992 to $520 million by the year 2000. Growth in nickel cadmium industrial batteries is projected to increase from $25 million in 1992 to $30 million by 2000. Growth for vented aviation nickel cadmium batteries is projected to increase from $33 million in 1992 to $35 million by 2000; this small amount of growth is caused by the increasing demand for sealed nickel cadmium batteries rather than the vented type.

Nickel metal hydride batteries are just entering the commercial market. Primary use of these batteries has been in support of personal notebook computers. Nickel metal hydride batteries are projected to reach a $100 million market by the year 2000.

7.2.7 Magnesium Manganese Dioxide Batteries

Magnesium manganese dioxide batteries are an old chemistry with limited applications and no strong foothold in either the military or commercial marketplace.

7.2.7.1 Magnesium Battery Marketplace Supply

Figure 7-13 illustrates two identified North American producers of military magnesium manganese dioxide batteries. The total sales data may reflect only battery sales, or it may reflect the sum of battery and other products sales (e.g. - electronic chargers/analyzers, electronic devices). The sales data from suppliers did not delineate between revenues for different products. Following the chart is a brief overview describing the company, its products, capabilities, and customers.

COMPANY INFORMATION			1993 COMPANY SALES			
Manufacturer Name	Parent/Owner Name	Battery Chemistry	Military Battery		Total Sales	
			M $	Trend	M $	Trend
ACR Electronics	North American Fund II	magnesium manganese dioxide	Not Disclosed	DOWN	Not Disclosed	UP
Rayovac	self	magnesium manganese dioxide	17	DOWN	Not Disclosed	UP

Figure 7-13. Companies in the Magnesium Battery Market

7.2.7.1.1 ACR Electronics Inc.

ACR was founded in 1956 by David H. Rush and now has two facilities in the Ft. Lauderdale area employing approximately 180 employees. ACR is owned by North American Fund II, which is a privately owned venture capital company consisting of a $50 million equity capital partnership of major institutional investors (University of Texas endowment funds, MacArthur Foundation, Ameritech Pension Trust, American Family Insurance).

ACR produces water-activated magnesium cuprous iodide batteries and magnesium manganese dioxide primary dry cell batteries. The Navy uses the magnesium manganese dioxide batteries for their Captor mines. ACR manufactures the magnesium manganese dioxide cell batteries at one facility and assembles the batteries at their second facility. Commercial and military magnesium manganese dioxide cells are manufactured on the same production line, but the production equipment is not automated and very antiquated.

ACR is the single source supplier of the magnesium manganese dioxide Navy Captor Mine (MK 125, 126, 127) battery. ACR has sold over 550,000 of these batteries to the Navy over the past 10 years. Twenty percent of ACR's sales are to the government and 80% to the commercial market. The Navy, Army, Marines, and Kelly Air Force Base each account for an equal portion of the total government sales.

7.2.7.1.2 Rayovac

Rayovac's primary demand is from commercial customers, but they also manufacture magnesium manganese dioxide batteries for the Army. The Army uses these batteries as a low cost alternative to lithium sulfur dioxide batteries for portable electronic devices used during training exercises. CECOM procures between 12,000 and 24,000 magnesium batteries per month under a multiple year contract. These batteries are manufactured on Rayovac's commercial production line. Rayovac also manufactures the MK117 underwater mine battery for the Naval Mine Warfare Engineering Activity (NMWEA).

Government agencies such as the DLA and GSA purchase common, commercial round cell batteries for various applications. Of the $17 million in military/government sales, Rayovac sold approximately one million dollars worth of batteries to commissaries and exchanges. Rayovac also received between four and five million dollars of R&D funding from the government in 1993 for several battery development projects.

7.2.7.2 Magnesium Battery Marketplace Demand

The magnesium chemistry has a limited customer market and only a few specialized applications that exist from older technologies. Figure 7-14 highlights some of these applications.

Typical Magnesium Battery Applications	
Military	**Commercial**
mines	locator beacons
portable electronics	portable electronics

Figure 7-14. Magnesium Battery Applications

7.2.7.2.1 Military customers

The military marketplace demand for magnesium manganese dioxide batteries is very small. This old chemistry supports Navy CAPTOR mines, although lithium thionyl chloride batteries have been safety certified for use in the next generation of CAPTOR mines. However, this retrofit program was canceled because there are not enough old CAPTOR mines in existence today to make this transition economical.

The Army uses commercial magnesium batteries for training exercises in portable electronics for non-tactical applications. These batteries can be used for tactical applications if the temperature is above 40° F. The significantly lower cost of the magnesium batteries compared to lithium sulfur dioxide primary batteries is the driving factor for continued use of these batteries in training equipment. As legacy equipment is replaced so too will this battery chemistry. For example, the Army presently uses magnesium batteries in the PRC 77 radio, but its replacement, the SINCGARS radio, will utilize lithium based batteries. The Army has worked with Rayovac to develop a better magnesium battery but has had little success.

7.2.7.2.2 Commercial customers

The commercial marketplace for magnesium manganese dioxide batteries is also very small. The batteries are used for emergency locator beacon applications and other portable electronics applications, but as these older technologies are replaced, it is likely the battery chemistry will disappear.

7.2.7.3 Magnesium Battery Marketplace Trends

The market for this chemistry is small and is not experiencing any type of resurgence. Most of the military demand is limited to cells from Rayovac and mine batteries from ACR

Electronics. This chemistry will continue to be used in limited fashion and may eventually be replaced with new chemistries.

7.3 Overall Marketplace Summary

Thermal batteries are presently exclusively military. They satisfy unique requirements of long shelf life, no maintenance requirements, and high power for short duration. Thermal batteries are "one shot" batteries typically installed as permanent components of a system or device. Such systems include missiles, torpedoes, aircraft emergency systems (e.g., ejection seats), and mines.

Presently North America has only one thermal battery manufacturer (Eagle-Picher), but Martin Marietta and Westinghouse Naval Systems Group are attempting to increase their thermal battery production capability in conjunction with their R&D efforts. SAFT America ceased thermal battery manufacturing at their Cockeysville, Maryland facility in December of 1993 for economic reasons. There are no present commercial applications for thermal batteries. Research is being performed to utilize thermal batteries for emergency power applications (e.g., in aircraft and automobiles), but present costs hinder these applications.

The emergence of lithium batteries in the market has taken longer than other battery technologies due mostly to thermodynamic limitations and environmental and safety concerns. Currently, the market for lithium batteries is small in comparison to the total battery market.

Lithium battery technology has played a larger role in military applications than commercial applications. A large portion of the military's primary battery budget has been for lithium batteries, mainly lithium sulfur dioxide. Lithium sulfur dioxide batteries supported a large number of portable electronics during the Gulf War. The war, along with subsequent contracts, have supplied the military with enough lithium sulfur dioxide batteries for the next three to five years. At that time the Army may look to replace the primary lithium sulfur dioxide battery with primary lithium manganese dioxide, and the Navy will look at lithium thionyl chloride as a replacement chemistry. This lack of demand for lithium sulfur dioxide batteries has left some manufacturers in a quandary. Some are attempting to transition to other lithium chemistries (secondary) while others are uncertain about their future.

The domestic consumer market for primary lithium batteries (lithium manganese dioxide and lithium thionyl chloride) is expected to increase over 50% by the year 2000. This increase will be due to increased applications in photographic devices, memory backup devices, and other

portable electronics. The domestic consumer market for secondary lithium batteries is expected to grow to $10 million by the year 2000, driven by the increased demand for consumer portable electronics and devices. Much of this demand is satisfied today by nickel cadmium batteries and soon by nickel metal hydride (because of its higher energy density). The consumer demand for longer service time presents an excellent opportunity for secondary lithium batteries.

The mercury battery family serves few military applications. These batteries support legacy systems, mines, and munitions and are being replaced with new systems with different battery chemistries. This chemistry will eventually disappear from the military arena. The commercial market also is phasing out mercury batteries due to their environmental unfriendliness.

Silver cadmium batteries are expensive and environmentally unfriendly. No research or programs on silver cadmium batteries were identified. This system will probably not exist in the future since there is very little demand for the chemistry. Silver zinc primary batteries probably will remain in existence to support specialized applications such as calculators, watches, medical devices, and some military applications. Silver zinc primary reserve batteries will remain as components to military missile systems.

Lead acid is the most widely used battery chemistry in the world. The military's primary uses for lead acid batteries are in vehicles, aircraft, submarines, surface ships, and standby power systems. The batteries are used for starting, lighting, and ignition systems; backup power for operating instruments; landing gear mechanisms; propulsion; and backup electrical power for missile silos. These military uses, coupled with the automotive and standby power commercial uses, have given the lead acid battery market overall stability. Manufacturers of military lead acid batteries realize that the defense dollar is shrinking but are confident in the well established commercial market.

Nickel cadmium batteries enjoy a stable market; they are very common in the portable consumer electronics and the aviation market. The nickel cadmium system has been around almost 100 years and is a proven high power, reliable, long life system.

The military uses or plans to implement sealed and ultra-low maintenance vented nickel cadmium batteries into aircraft applications for engine starting, emergency power, and utility power (i.e., electric power while the aircraft engine is shut down). The military is retrofitting some aircraft that contain vented nickel cadmium batteries with sealed nickel cadmium batteries; the sealed system eliminates the maintenance procedure of adding liquid electrolyte. The military plans

continued use of nickel cadmium batteries until the nickel metal hydride chemistry reaches maturity.

The nickel cadmium commercial market is fairly stable supporting commercial aircraft, portable consumer electronics, and other applications such as standby power. Batteries used in the consumer portable electronics market are distinctly different in configuration than aviation batteries, and the identified manufacturers of nickel cadmium aviation batteries do not manufacture nickel cadmium batteries for the consumer portable electronics market.

The largest impact on the future of nickel cadmium batteries most likely will stem from environmental concerns. Cadmium is environmentally unfriendly and necessitates specialized handling and recycling procedures. The cost associated in dealing with cadmium and its environmental concerns may lead to the replacement of the system with one that is improved and environmentally friendly.

Magnesium manganese dioxide is a very outdated chemistry with a very small commercial and military market. The only identified military use of these batteries is in the Navy's CAPTOR mines and by the Army for support of portable electronics during training exercises. The use of these batteries for training is dictated by their significantly lower cost compared to lithium primary batteries. Lithium thionyl chloride batteries were identified as a potential replacement for the next generation of CAPTOR mines but that program was never completed; the small number of existing mines and the cost of the lithium thionyl chloride battery did not make this retrofit economically feasible.

Commercially, magnesium manganese dioxide batteries are used in emergency locator beacons. The one identified manufacturer, who is the sole supplier of the CAPTOR mine battery, has stated that if military demand for magnesium manganese dioxide batteries were nonexistent there would not be enough commercial market to sustain this capability.

Figure 7-15 provides a summary of the battery chemistry marketplace.

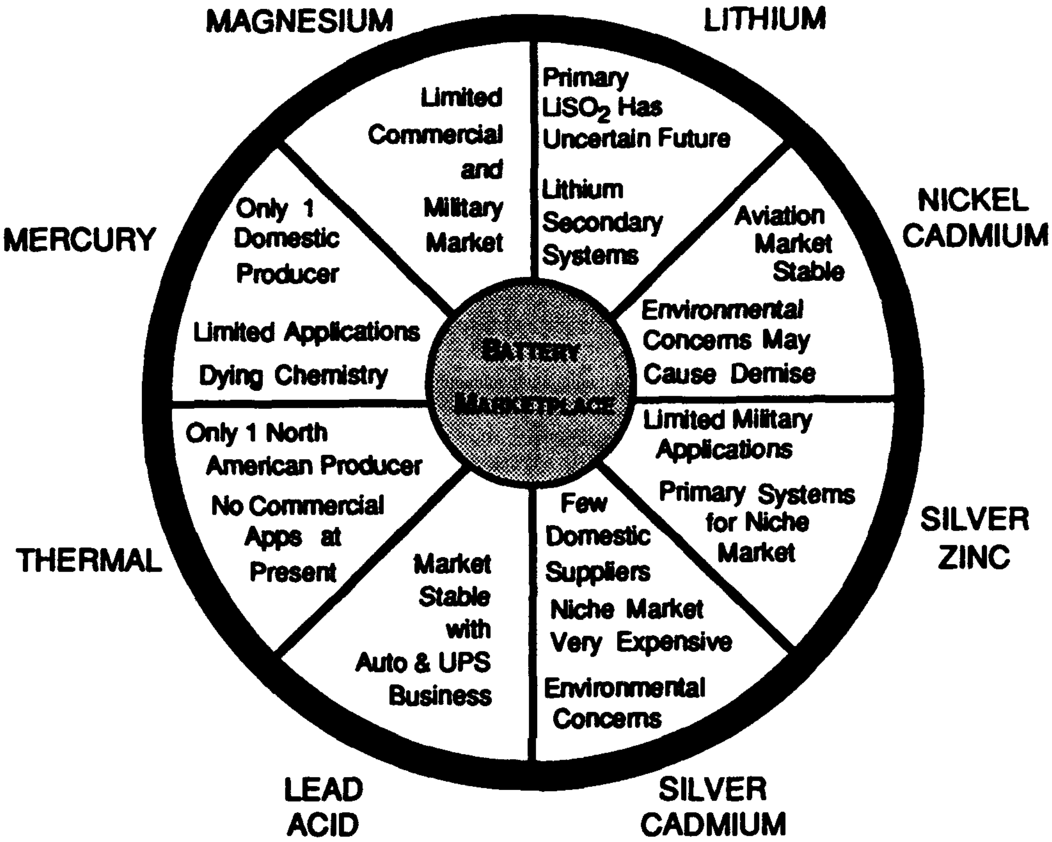

Figure 7-15. Battery Marketplace Summary

8.0 BATTERY RESEARCH AND DEVELOPMENT ACTIVITY

This section provides an overview of battery research and development activities. It highlights the major battery focus areas of the departments and agencies and outlines, by chemistry, the ongoing R&D efforts. A list of the companies, universities, and laboratories currently involved in battery R&D is also provided by chemistry.

8.1 Overview of R&D Areas of Concentration

This section provides an overview of current areas of battery R&D activity of the military services, government agencies, Canadian Department of National Defence, and commercial enterprises. As highlighted in this section, many organizations are pursuing R&D efforts involving similar battery chemistries, though each is pursuing research to fulfill unique, specific objectives to further a particular mission.

8.1.1 Army

The Army procures and uses over 700,000 batteries per year for tactical, contingency, training missions, and exercises at a cost of over $94,000,000. These batteries are primary, rechargeable, or reserve types and utilize over one dozen chemistries. The Army Research Laboratory (ARL) is responsible for research, development, and battery assignment of most battery types within the Army Materiel Command. The Communications Electronics Command (CECOM) procures approximately 150 primary battery types and 80 rechargeable battery types, mostly for C4I equipment and aviation applications. CECOM also procures lithium batteries for the Marine Corps for use in equipment designed by the Army. These batteries support over 1000 pieces of equipment and systems. The Tank Automotive Command (TACOM) procures 10 rechargeable batteries for vehicles and generators.

The Army's research and development budget for batteries and battery technologies (but not conclusive) is as follows:

- 6.1 Funding: High Energy Storage Technology
  1993 - $ 440,000 — 1994 - $1.044 million — 1995 - $1.114 million
- 6.2 Funding: High Energy Batteries and Alternative Energy Sources
  1993 - $1.7 million — 1994 - $1.795 million — 1995 - $2.243 million

- 6.2 Funding: High Energy Batteries and Capacitors

  1993 - $775,000 1994 - $785,000 1995 - $643,000

- 6.2 Funding: Battery Technology

  1993 - $3.65 million 1994 - $3 million

  1995 - $0.00 (No Congressional funding has been assigned to this category at this time, though it is anticipated).

The Electronic and Power Sources Directorate of Army Research Laboratories (ARL) conducts the Army's battery research and development and testing activities. Primary and rechargeable battery research is handled at ARL's Fort Monmouth location; thermal and reserve battery work is handled at Harry Diamond Laboratories.

Facing the reality of Army downsizing, reduced demands, and increased focus on costs, the Army's goal in the battery arena is to move away from military unique technologies which require a dedicated production base. Key objectives are to lower O&S costs, strive towards dual use technologies, use more automated production, standardize batteries, and make batteries safer by eliminating hazardous materials. Improvements are sought in the areas of:

- increased energy and power densities,
- increased cycle life,
- increased shelf life,
- increased low and high temperature operation,
- increased reliability,
- increased state-of-charge capability,
- reduced test needs, and
- increased commercial availability.

In the short term, this probably will entail fielding interim rechargeable batteries, replacing mercury and zinc-carbon batteries, fielding improved battery chargers and power supplies, reducing hazardous waste streams, reducing disposal costs, and replacing nickel cadmium aircraft batteries. CECOM has begun to identify old equipment that can be phased out along with its unique batteries. CECOM is investigating the use of alternative batteries for old equipment that is worth modifying. CECOM also is in the process of identifying candidate mercury batteries for replacement by other chemistries. The Army's long range goals are to:

- drive designs to use less power, emphasizing battery selection and power management in initial end item design efforts and enabling designers to use standard batteries
- base next generation of power sources on dual use technologies

- standardize chemistries and configurations to field a family of
  - primary batteries
  - rechargeable batteries
  - aircraft batteries
- capitalize on standard consumer configurations
- field a universal battery charger
- minimize proliferation of new batteries (CECOM purged its inventory from 473 non-rechargeable battery types to 202 in 1987)
- continue development of a universal battery
- eliminate hazardous waste
- make state of charge internal to end item.

The Army would like to satisfy its training battery requirements by using a very low cost, high energy density primary battery; a low cost, improved energy density, lightweight rechargeable battery; or a higher capacity per cycle rechargeable battery. The National Training Center ultimately would like to have a battery that offers 120 hours of continuous operation, is non hazardous, is economical, and weighs no more than seven pounds. They also would like to provide the soldier with the ability to charge the battery in the field. At present, the Center spends $2 million a month for primary batteries for its training exercises.

Rechargeable batteries the Army is considering for future production are lithium ion chemistries, nickel-zinc chemistries, alkaline manganese chemistries, and metallic lithium chemistries.

8.1.2 Air Force

Sites conducting battery electrochemistry R&D within the Air Force are Wright Laboratory, Phillips Laboratory, and Frank J. Seiler Research Laboratory. Wright Laboratory's primary focus is on power for aviation systems, such as aircraft, aircraft ground support equipment, aircraft tactical weapons systems, life support/survival equipment, and unmanned aerial vehicles (UAVs). Wright Patterson's long term objectives are to focus on development of a lithium based polymer battery, a high voltage thermal cell, and a bipolar battery for More Electric Aircraft, weapons, and tanks.

Phillips Laboratory's work revolves around power for space and strategic systems such as satellites, space based weapons, on-board strategic missiles, and strategic missile ground power. Their main area of emphasis is lithium polymer rechargeable batteries.

Frank J. Seiler Research Laboratory concentrates on more basic research, such as electrode processes, electrochemical materials, and electrocatalysts. An important major thrust of the Air Force is to develop environmentally friendly batteries and focus on pollution prevention and clean-up.

8.1.3 Navy

The Navy spends between $20 to $30 million annually on battery research and development. This includes basic research, exploratory research, advanced research, prototypes, and technical and operational evaluation. The Navy believes that because of new equipment designs and increased demands on existing systems, lithium-based power sources are required. Major areas of Navy battery technology interest are:

- Secondary batteries (lithium, lithium ion, ZnAgO, NiCd, lead acid)
- High energy density batteries (lithium/oxyhalides)
- High power density batteries (ZnAgO, thermals, lithium, sea water systems)
- Advanced materials for power sources.

The Naval Surface Warfare Centers (NSWC) conduct a full spectrum of RDT&E in power sources and corrosion and are responsible for basic R&D efforts for shipboard power sources. The NSWCs have attempted to apply low-cost, commercially available technologies to military systems for several decades in order to decrease military systems' costs.

Present and future Navy battery thrusts entail advanced non-lithium rechargeable batteries, polymer electrolytes, fuel cells, sea water batteries, lithium thermal batteries, rechargeable lithium batteries, high pulse power lithium/oxyhalide batteries, and continuous improvement of field technologies.

The Navy currently operates the Standard Hardware Acquisition and Reliability Program (SHARP), a Navy-wide logistics technology development effort aimed at reducing acquisition costs, support costs, and implementation risks of military electronic systems while increasing the performance, capability, reliability, maintainability, and readiness of these systems. To lower lifecycle costs of electronic hardware, the program aims at technology transition, standardization,

and reliability enhancements. In particular, the SHARP program focuses on developing, standardizing, and documenting military specifications, standardizing the family of mine batteries, standardizing battery chargers, and enhancing nickel metal hydride, lithium ion, composite nickel cadmium, and lead acid battery technologies.

8.1.4 Department of Energy

Sandia National Laboratories (SNL) is a major player in DOE's weapons battery program. Their main thrusts involve thermal batteries, lithium/sulfur dioxide batteries, lithium/thionyl chloride batteries, and double layer capacitors. SNL's battery activities center on research, advanced development, design, prototype fabrication, testing, production support, stockpile surveillance, dismantlement, and disposal.

DOE's Office of Basic Energy Sciences is involved in the Advanced Battery Technology Research and Development Program, a relatively new program with a mandate to develop new generic battery technology for a wide range of applications. Their main areas of emphasis are on improvements in battery size, weight, and recharge cycles for non-automotive applications. Current research on advanced battery technologies entails new battery components, concepts, and systems and characterization of methodologies in the areas of electrochemical systems and batteries; computational chemistry, modeling, and simulation; and materials characterization. The FY 1993 and 1994 funding for the Basic Energy Sciences program is approximately $3.5 million and is expected to remain stable or increase slightly in FY 1995.

Lawrence Berkeley Laboratory is responsible for the Exploratory Research Program. DOE's exploratory technology research program is organized into the following program thrusts:

- exploratory cell research
  - new electrochemical couples
  - high performance systems for consideration by the USABC
- applied science and research
  - characterization of cell components and phenomena
  - development of corrosion-resistant materials
  - mathematical modeling of cells and processes
- air systems research
  - electrocatalysis of oxygen reduction and methanol oxidation
  - development of novel electrode structures
  - PEM fuel cell R&D.

The U.S. Department of Energy sponsors the Energy Electric and Hybrid Vehicles Program. The program has three main objectives: promote basic and applied research on electric and hybrid vehicle batteries, controls, and motors; determine optimum overall electric and hybrid vehicle design; and design vehicles that emphasize durability, length of practical lifetime, ease of repair, and interchangeability of parts.

DOE hopes that its transportation technologies program aids in reducing transportation energy demand by improving vehicle and system fuel use efficiency, reducing oil vulnerability by providing alternative transportation fuels and utilization technologies, and producing tangible marketable results (vehicles and fuels) by the year 2000. The major barrier to commercialization of electric vehicles is the lack of a low-cost, high-performance battery. Much of the ongoing research regarding electric vehicles is focused on improving battery performance. The key is to develop a battery which has an acceptable cruising range on a single battery charge and to have the capability for rapid battery recharging.

The U.S. Advanced Battery Consortium (USABC) is very active in electric vehicle R&D. The USABC was formed in 1991 between Chrysler, Ford, General Motors, DOE, and the Electric Power Research Institute to develop advanced electric vehicle batteries through the sharing of technology and costs. Its program objectives are to accelerate market potential of electric vehicles by jointly researching the most promising advanced battery alternatives, to establish a capability for a U.S. advanced battery manufacturing industry, and to demonstrate design feasibility of an advanced battery to meet long-term criteria in 1994.

DOE's exploratory technology research in support of advanced battery development is directed at the following four objectives:

- conduct applied research to address problems encountered in the development of advanced rechargeable batteries
- develop improved material and components for use in advanced batteries, fuel cells, and ultracapacitors
- explore promising long-term battery, fuel cell, and ultracapacitor technologies in order to provide alternatives to the USABC
- Conduct research into electrochemical phenomena that limit the performance and life of electrochemical energy storage and conversion systems.

Research is geared toward aqueous and non-aqueous battery systems, fuel cells, ultracapacitors, and exploratory, cross-cutting initiatives.

8.1.5 Advanced Research Projects Agency (ARPA)

ARPA's main areas of interest in batteries are developing lithium ion and lithium solid polymer batteries. ARPA also oversees the Technology Reinvestment Program (TRP). The mission of the TRP is to stimulate the transition to a growing, integrated, national industrial capability that provides the most advanced, affordable, military systems and the most competitive commercial products through the development of dual-use product and process technologies. One of the key dual use technology areas of the TRP Technology Development Activity Area is advanced battery technology. This initiative is focused on developing battery technologies that offer greater energy densities for man-portable applications. Among those initiatives are continuous thin-film manufacturing techniques for lithium/polymer batteries that are safe, rechargeable, and less expensive than batteries currently available for military or commercial use.

The TRP also has identified vehicle technology as a technology focus area. In FY 1993, the Natural Gas program had $6.4 million for military vehicle technology and demonstration and $2.8 million for a next generation auxiliary power unit for electric vehicle range extension. The FY 1994 program has $46.2 million for further technology developments.

8.1.6 NASA

NASA's Jet Propulsion Laboratories (JPL) deals with advanced rechargeable batteries for LEO, GEO, and planetary applications. Ongoing programs at JPL are:

- lithium titanium disulfide ($LiTiS_2$) rechargeable cells
- lithium ion rechargeable cells
- lithium polymer electrolyte rechargeable cells
- nickel metal hydride rechargeable cell technology development
- moderate temperature sodium metal chloride rechargeable cells
- nickel cadmium cell/battery flight simulation and stress testing
- nickel cadmium battery performance/prediction model
- Topex battery operations
- Mars Pathfinder batteries.

Specific areas of improvement NASA would like to achieve regarding their current battery systems include reducing weight and volume, increasing operational life, increasing specific power and power density, increasing active storage and charge retention, and extending operation to extreme environments. Several advanced battery systems are under development, including lithium titanium disulfide, lithium ion, nickel metal hydride, and sodium metal chloride. At present, small to medium capacity cells of these advanced battery technologies are available, but they are usually handmade or batch processed and the cycle life generally is limited to 1,000 cycles. Advances in charge control are needed to balance these cells in the battery. In addition, safety and abuse effects need to be thoroughly examined.

NASA has established an Aerospace Flight Battery Systems Program to enhance the safety, reliability, and performance of their aerospace primary and secondary batteries, as well as battery power systems. Part of this effort centers on bringing forth advanced technology for flight use and ensuring that safe, reliable batteries are available for NASA's future missions. Their approach is to:

- increase the fundamental understanding of primary and secondary cells
- provide for improved cell/battery manufacturing process control, specifically in the area of secondary nickel-cadmium and nickel-hydrogen batteries
- open and maintain communication lines within NASA and the aerospace community
- provide for qualification of new technologies as they become available
- implement checks and balances for the verification of various cell technologies.

8.1.7 Department of National Defence (DND), Canada

For 1993/1994, DND will spend approximately $10 to $13 million for batteries. DND currently funds $1.18M annually for battery R&D. Their emphasis is on primary batteries (35% of current funding), advanced rechargeable batteries (45%), and solid polymer fuel cells (20%). In developing power sources for specific applications, DND is aiming to improve shelf life, energy density, safety, reliability, and low temperature performance. DND R&D efforts in the battery arena are focused on fulfilling the need for:

- high mobility and no maintenance
- increased power demand and pulse power
- Arctic operational capability
- person portable, 500W low cost power supply

- reduced detectability of generator sets
- reduced cost
- state-of-health battery monitoring devices
- environmental acceptability.

Battery issues the Canadians consider critical and need to be resolved are state-of-charge batteries, deficient low temperature operation, and fast and front line smart chargers.

Conducting this R&D for the Canadian government are Canadian universities (53%), Canadian non-profit institutions (29%), Canadian firms (10%), and the Royal Military College (8%). Primary battery R&D work is underway at the University of Ottawa, INRS-Energie, and Farrington Lockwood. Advanced rechargeable battery work is going on at the National Research Council, IREQ, and the University of Ottawa. Solid polymer fuel cell R&D is being conducted at RMC, Ecole Polytechnique, and Ballard.

DND is interested in Polymer Electrolyte Membrane Fuel Cells (PEMFC). They consider PEMFCs to have the greatest potential for miniaturization and Collaborative Research Into Small Arms Technology (CRISAT) applications. The PEMFCs produce high power density at temperatures below 100 degrees Celsius, allowing fast start-up and immediate response to changes in the demand for power. One of the key issues associated with PEMFC is the supply of hydrogen in a safe, cheap, and lightweight package. To this end, Canada has proposed to NATO that they initiate R&D projects on hydrogen storage/production means, including pressurized gas, liquid hydrogen, disposable and rechargeable hydrides, and miniaturized reformers.

DND foresees its future battery activities centering on lithium primary systems, lithium rechargeable systems, and solid polymer fuel cells. DND also is tracking emerging technologies such as the supercapacitor, zinc manganese dioxide rechargeable, and nickel hydride rechargeable, and they are funding a major project at Alupower to continue the development of an aluminum air battery.

8.1.8 Other Electric Vehicle Battery Research Efforts

The Advanced Lead Acid Battery Consortium is active in electric vehicle battery research. They consider lead acid batteries an inexpensive, safe, recyclable, currently available, and proven

technology for powering near-term electric vehicles. Other U.S. organizations in place to address battery technology include the following:

- the U.S. Council for Automotive Research
- the Electric Power Institute
- the Electric Vehicle Association of the Americas
- the Electric Transportation Coalition
- Calstart
- the Showcase EV Program
- the Infrastructure Program
- the Electric Bus/Mass Transit Program
- the Neighborhood EV Program
- the University and Federal Lab Research Program
- the Discretionary R&D Program
- the Chesapeake Consortium
- Texstart
- the National Station Car Consortium
- the Electric Transit Vehicle Institute.

On the international front, the following are involved in electric vehicle battery R&D efforts:

- The Chinese Electric Vehicle Institution
- The European Electric Road Vehicle Association
- The German Federal Ministry for Research and Technology
- Italy's Electrochemical Energy Storage Program - This program is broken down into current battery technology (lead acid, nickel cadmium, and nickel iron) and advanced battery technology (sodium sulfur, advanced alkaline, and lithium)
- The Japan Electric Vehicle Association
- The Japanese Electric Vehicle Council
- Sweden's National Board for Industrial and Technical Development
- Canada, The Electrochemical Science and Technology Center (ESTCO), University of Ottawa

8.2 Thermal Chemistries

The military services are the only customer for thermal batteries; there are no commercial requirements for thermal batteries at this time. These types of batteries are for one time use only

and provide power for electronics, heaters, pyrotechnic squibs, guidance systems, capacitor charging, and motors. The services use these batteries primarily for missile applications such as the TOMAHAWK, SIDEWINDER, AMRAAM, PATRIOT, SPARROW, and TOW.

However, thermal batteries are being looked at for applications outside of ordnance support. Two identified applications are emergency power on aircraft and emergency power for automobiles. The development of More Electric Aircraft (MEA) should increase the demand for thermal batteries. At present, the activation of the landing gear is done hydraulically, with some sort of backup system. In a lot of cases, this backup system is manual. In an MEA, the activation of the landing gear will occur via electric actuators. Aircraft employing this new technology will require improved back-up power systems. Recent advances in thermal battery performance, such as longer operating life, may provide the answer as a long shelf life, high energy emergency backup system for these applications. The same is true for automobiles. The use of electric brakes and control actuators could provide further uses for thermal batteries as backup systems. However, R&D activities for automobile applications are not being actively pursued at this time because the cost of the battery is considered too prohibitive to justify its use.

8.2.1 Army

The Army is concentrating its efforts in the thermal battery arena on:

- Increasing the energy density and reducing the weight and volume of thermal batteries by better thermal management
- Developing a spin-stable thermal battery, thereby extending these high power batteries to artillery and mortar applications
- Identifying lower thermal conductivity materials of construction
- Creating novel electrolyte systems that would extend useful service life
- Improving and modernizing a demonstrated concept for a thermal battery heated by sterno cans.

8.2.2 Air Force

Primary Air Force thermal battery programs are listed in Table 8-1.

COMPANY	PROGRAM
Eagle-Picher, Joplin, MO	onboard thermal batteries for AMRAAM and small intercontinental missile (offers potential to replace Li/SOCl2 reserve battery)
Molten Salt Technology, Inc., Knoxville, TN	demonstrate the feasibility of utilizing the S9(IV) cathode of the Na/S(IV) rechargeable cell for a thermal cathode on a thermal battery for onboard weapons power and aircraft emergency power

Table 8-1. Air Force Thermal Battery Programs

The Air Force is interested in further lithium based battery development for hydrazine EPU replacement for aircraft emergency power and reserve AgO-Zn replacement for glide bombs. Future Air Force projects will focus on possible thermal batteries for the AGM-130 missile and for A/C emergency power.

8.2.3 Navy

The Navy is funding thermal battery R&D efforts to improve operating life to over one hour on a single heating, provide power up to 7,000 watts from a battery package about the size of two D cells, and provide more energy for the thermal systems.

Eagle Picher, together with Spartan, is pursuing thermal batteries that offer a high energy density and a moderate discharge rate to improve vehicle propulsion and countermeasure for underwater mines. SAFT is studying special purpose batteries (the 7,000 watt pulse battery) for low frequency sonobuoys. Westinghouse is working in conjunction with Magnavox to develop a thermal battery for sonobuoys.

8.2.4 NASA

NASA's Jet Propulsion Laboratory is addressing the potential of a thermal battery to supplement pulse loads of the Mars Pathfinder during entry, descent, and landing.

8.2.5 Department of Energy

Weapon applications of DOE's thermal batteries are radar, programmers, timers, fire sets, spin rocket motors, parachute deployment, reefing line cutters, telemetry, command disable functions, DOE/DoD joint test assemblies, and safe/arm systems. Sandia National Laboratory is DOE's focal point for thermal battery R&D. Their activities include design/development, production support, consulting, modeling, research/advanced development, NWC reconfiguration, and dismantlement. Specific areas of study are listed below:

- Improved electrolytes
  - Lower melting: longer life
  - Higher conductivity: high current capability
- New cathode materials
  - Improved thermal stability
  - Lower polarization
- Advanced insulation (Aerogel)
- Alternative heat sources
  - CuO/Al
  - Secondary heating
- Environmental, safety, and health issues.

Planned future thermal battery activities are to perform reconfiguration assignments, such as limited manufacturing, procurement and surveillance testing; continue research/advanced development; and continue DoD support in efforts such as the tri-services standoff attack missile and the Navy sonobuoy.

8.2.6 Industry

Eagle Picher has just begun production on thermal batteries which have virtually unlimited shelf lives and can run up to two hours. The initial application for this technology is sonobuoys, but they are projected for use in More Electric Aircraft (MEA). Martin Marietta recently acquired the former Department of Energy thermal battery manufacturing facility in Pinellas, Florida. The

DOE is phasing out operation in Pinellas while funding Martin Marietta to start up a thermal battery manufacturing plant. Westinghouse Naval Systems Group is also looking into thermal battery development. Tables 8-2 and 8-3 list North American and foreign players in the thermal battery market.

COUNTRY	INDUSTRY	UNIVERSITY
France	Aerospatiale	
Germany	Diehl and Eagle Picher	
Israel	Israel Armament Development Authority	Israel Institute of Technology
Japan	Matsushita Battery Industrial Company	
Scotland	MSA Ltd.	
Sweden	Catella Generics	
	SAAB Military Aircraft	
Switzerland	LeClanche	

Table 8-2. Foreign Thermal Chemistries R&D Players

INDUSTRY	LABORATORIES
Eagle Picher	Army Research Laboratory
EG&G Mound Applied Technologies	MICOM
EIC Laboratories	Naval Surface Warfare Center - White Oak
Martin Marietta	Naval Surface Warfare Center - Crane
Whittaker Power Storage System	Sandia National Laboratories - Would like to target development within two years a thermal battery which will run for four hours
Yardney Technical Products	U.S. Army Harry Diamond Laboratory

Table 8-3. North American Thermal Chemistries R&D Players

8.3 Lithium

A large part of the military's battery budget is for lithium batteries. The major focus of military research and development activities in lithium based batteries is toward improved safety and performance of existing primary systems and development of secondary lithium systems. The trend in the military services is to develop the next generation of lithium chemistry batteries and phase out lithium sulfur dioxide system. Primary chemistries of particular interest include lithium manganese dioxide, lithium thionyl chloride, lithium sulfuryl chloride, and lithium carbon monofluoride. Lithium manganese dioxide is the most widely produced and cost effective lithium system available today for consumer applications. This chemistry will probably be used extensively in Army applications, while the Navy will be the major user of the lithium thionyl chloride chemistry.

The secondary systems being addressed include lithium ion and lithium polymer batteries. Lithium ion systems are used in very few applications currently while lithium polymer systems are still under development. Lithium ion batteries have over three times the energy content per weight than nickel cadmium batteries, exhibit a very significant operating cost benefit over primary batteries, are environmentally less reactive, and have no free lithium metal. All of these aspects present reasons for a push towards maturation of this chemistry. SONY in Japan introduced this chemistry to the commercial market in 1991 for use in notebook computers, camcorders, and cellular telephones. Development of lithium ion cells has become the main focus of Japanese electronics manufacturers who are considered to be dominant in this technology.

Lithium polymer batteries could exceed the energy capacity of lithium ion batteries since they do not need a carbon or graphite anode as a storage material for the lithium. Lithium would constitute the entire anode. In order for this technology to become a reality, polymers would have to be found that are more conductive and do not degrade after approximately 150 cycles.

8.3.1 Army

Currently, the Army is using second and third generation lithium sulfur dioxide chemistries as their primary batteries. ARL's goals for primary batteries are to make them safe, cost effective, high power/high energy, all temperature performance, environmentally friendly, and offering the potential for dual uses. The Army's primary battery thrusts are:

- lithium/sulfur dioxide
- lithium/thionyl chloride

- lithium/manganese dioxide
  - cylindrical
  - pouch
- lithium/sulfuryl chloride.

Lithium sulfur dioxide primary batteries are standard Army batteries. The Army is the main customer for lithium sulfur dioxide batteries. These batteries are a mature technology that is regarded as safe, reliable, capable of achieving all temperature performance, and having a shelf life of over ten years.

The lithium manganese dioxide battery is regarded as the most probable candidate to replace the lithium sulfur dioxide line. Lithium manganese dioxide (cylindrical) is commercially available, has an energy density 50 percent higher than lithium sulfur dioxide, and has a discharge rate 50 percent higher than lithium sulfur dioxide. They are also much safer because they are not under pressure and do not contain toxic electrolytes like lithium sulfur dioxide and lithium thionyl chloride batteries. Some performance compared to a lithium sulfur dioxide battery is lost in the lithium manganese dioxide battery, primarily in cold weather, but they are projected to offer twice the life of the lithium sulfur dioxide batteries at less cost. Still at issue is the weight of the lithium manganese dioxide versus the lithium sulfur dioxide and some safety concerns. Improvement also is needed in its low temperature capabilities.

The lithium manganese dioxide (pouch) is believed to offer the ultimate in safety, the highest dual use potential, and the lowest cost potential. However, it is in the early stages of development, and there are many unknowns such as hermeticity, shelf life, low temperature performance, thermal behavior, and stack pressure/contacts. ARL currently is evaluating the state-of-the-art foreign technology for lithium manganese dioxide cylindrical cells. Commercially-available cells from Dowty and Hoppecke have been tested. These samples' room temperature performance is similar to lithium sulfur dioxide, but their low temperature performance would need to be improved.

Other chemistries attractive to the Army are lithium thionyl chloride and lithium sulfuryl chloride. Lithium thionyl chloride chemistries are appealing because they offer high power, all temperature performance, high rate pulse design, and instant start capability. Their application currently is limited to laser devices and their shelf life is unknown. They are a candidate for the soldier system. Presently CECOM uses lithium thionyl chloride batteries, obtained from SAFT (but the cells are actually manufactured in France), in very limited applications. Lithium sulfuryl

chloride is a maximum power/energy lithium system and is considered the most promising lithium system to meet soldier system requirements. Concerns with this particular chemistry include shelf life (without refrigeration), low temperature performance, safety, and rate capability at all temperatures.

Table 8-4 below lists current ARL primary battery R&D projects.

COMPANY	PROGRAM
SAFT	instant start HRP Li/SOCCl2
Ballard	lithium manganese dioxide cylindrical
PCI	lithium manganese dioxide pouch cell
Ultralife	lithium manganese dioxide pouch cell

Table 8-4. Primary Lithium Battery R&D Projects

SAFT's lithium thionyl chloride prototypes are being developed for laser systems and laser counter measure applications. This chemistry performs well in cold weather and offers a higher energy density. Ballard Battery Systems Corporation's two year, $565,000 effort is to produce a safe, cost effective primary lithium manganese dioxide battery for communications/electronics equipment applications. The lithium manganese dioxide battery will have 30 percent more power than a lithium sulfur dioxide battery and could be used as its replacement. PCI and Ultralife have both been funded by the Army to make this soft sided pouch style lithium manganese dioxide battery chemistry.

The Army is planning to transition to a lithium polymer (foil cell) primary battery by 1998. The foil laminate packaging is appealing because it will reduce the cost and weight of lithium primary batteries for military batteries. It involves placing the lithium battery in a plasticized foil, a major departure from the standard metal casing. Barriers include degrading interfaces, high power/low temperature performance, low energy cathodes, and high weight of inerts.

The Army has invested significantly in researching lightweight power sources for the future soldier system, the 21st Century Land Warrior. ARL currently is examining sulfuryl chloride batteries or some version of a pouch battery for the maximum energy density battery for this system. They are examining a backpack arrangement with a battery life of 6 to 24 hours.

The Army will continue to use lithium battery chemistries for the Single Channel Ground and Airborne Radio System (SINCGARS) because they consider lithium to be the only available battery technology that meets the SINCGARS mission requirements. These requirements include 24-hour continuous operation, weight less than 20 pounds, the ability to handle both high and low temperatures, and capability to transmit four watts of power at the antenna. Challenges in advancing this technology include decreasing the weight (which currently accounts for about 12 percent of the manpack weight), being able to use low power components and low cost monitoring devices, expanding the life of the rechargeable batteries, and lowering the cost. In recent developments, the Army has been able to reduce the SINCGARS power consumption by 25 percent, which will help extend the battery life. The Army also has developed a standard family of non-rechargeable lithium batteries that ARL assigns to new equipment.

Regarding rechargeable batteries for C4I applications, the Army has placed emphasis on using a battery that offers dual use, low cost, and early availability. The nickel metal hydride battery is being implemented for near term use, improved lithium ion batteries for mid-term use, and lithium polymer cells for far term use. Rechargeable alkaline zinc magnesium dioxide batteries are a possibility for special applications. Active ARL rechargeable battery programs include:

- EIC - rechargeable lithium battery with solid electrolyte
- Covalent - high rate, solid inorganic polymer electrolyte-based bipolar batteries
- Rayovac - low cost rechargeable alkaline battery.

The lithium ion batteries projected for possible use by the Army will have the same chemistries used in the commercial market, but the configuration and packaging will be unique and, hence, the price will be higher than the consumer market. ARL is working with SAFT and Rayovac on developing a rechargeable lithium ion battery. Concerns with using this new chemistry include safety issues regarding flammable electrolytes and cost effectiveness. The cost effectiveness issue will address commercial demand. Improvements are being sought in energy density and low temperature operation. Tadiran, an Israel-owned company, is developing a lithium ion battery independently and will provide ARL with samples for testing.

EIC and Covalent have both received funding to conduct lithium polymer R&D. ARPA will be sponsoring some lithium polymer work in the near future as well.

ARL also is studying rechargeable pulse power/high power batteries for electric guns and electromagnetic armor. Westinghouse and SAFT are involved in this effort.

Another research program currently underway in the Army is development of a lithium based liquid reserve battery that has a longer operating life. These reserve batteries are used primarily in munitions. In a reserve battery, the electrolyte is kept separate from the active material and mixed together with the material when the item is put into use. These batteries are an alternative to environmentally and economically endangered lead/fluoroboric acid systems. The ultimate goal of this project is to use commercially available primary batteries instead of custom liquid reserve batteries. An in-process evaluation of storage lifetimes of commercially available button cells is underway.

8.3.2 Air Force

Air Force plans include lithium rechargeable batteries (inorganic and polymer) for More Electric Aircraft, life support/survival, special operation forces, aerospace medical devices, RVs, and sensors and lithium primary inorganic batteries for special operational forces, fuses, and on-board tactical weapons. Wright Laboratories' efforts include high voltage system thermal chemistries, inorganic electrolytes for lithium rechargeable batteries, primary and secondary lithium-ion polymer batteries, and inorganic lithium primary batteries.

Table 8-5 lists current programs underway that are in conjunction with Wright Laboratory.

COMPANY	PROGRAM
Lithium Energy Associated	rechargeable lithium copper chloride battery with inorganic electrolyte for ICBM emergency/survival power
	low temperature, lightweight rechargeable lithium battery for possible use in life support devices, transmitters, beacons, laptop computers and portable power tools

Table 8-5. Air Force Lithium R&D Projects (Wright Laboratory)

[illegible]	[illegible]
Ballard Battery Systems	rechargeable Li/SO2 battery for use in aviation, tactical and strategic weapon systems (this four-year, $3.5 million effort is jointly funded by Industry Science and Technology Canada.)
Yardney Technical Products	rechargeable lithium batteries for use in aviation, tactical, and strategic weapons systems
University of Rome (Scrosati)	characterization of the lithium/polymer electrolyte interface
Technical University of Warsaw (Florjanczyk)	low temperature polymer electrolytes that are electrochemically compatible with lithium systems
Wright Laboratory in-house (Scanlon)	non-aqueous electrolyte battery research involving development of an ionically conducting polymer electrolyte with good lithium electrode/electrolyte interfacial stability
SAFT America, Inc.	a rechargeable, high energy density, lithium ion/LiMo (LiC/CiNiO) battery for military and commercial consumption

Table 8-5, Cont. Air Force Lithium R&D Projects (Wright Laboratory)

COMPANY	PROGRAM
Sage Corporation	use Sol-gel techniques to grow cathode materials, in powdered form, for use in lithium rechargeable batteries for portable power applications.
Redox Batteries, Inc.	develop carbon (graphite) fiber anodes capable of reversibly accepting lithium ions without performance degradation during cycling. Result will be a high energy density, long life lithium ion battery with improved performance and safety characteristics, made from environmentally friendly materials.
Covalent Associates	use lithium manganese oxides as cathode materials in model rechargeable lithium ion batteries, resulting in a battery that offers a higher energy density, is more stable, and is environmentally friendly.
UDRI	explore polymer electrolyte with high ionic conductivity, high transport number and good electrode/electrolyte stability for use in a high energy density rechargeable battery for dual use capability.
Indian Institute of Science	investigate the failure mechanism of polymer electrolytes as a function of time. Final goal of the AF is to develop a rechargeable lithium battery with dual use capabilities.

Table 8-5, Cont. Air Force Lithium R&D Projects (Wright Laboratory)

The Air Force also has embarked on a program to develop a transient, 3-D heat and mass transfer mathematical model of a lithium/polymer electrolyte rechargeable battery. This model will be used to optimize battery designs for various applications requirements. Scheduled completion date for this model is May of 1995.

In the future, Wright Laboratories will be exploring liquid and polymer electrolytes for use in advanced aircraft batteries (bipolar); life support/survival, special operations, aerospace medical, and RV batteries (monopolar and bipolar); and potential dual use applications (lithium secondary and primary of varying electrolyte systems). Some potential commercial applications for these batteries are automotive traction, aircraft, medical (pacemakers), electronics, and satellites.

Phillips Laboratory has several contractual development efforts in place involving solid state batteries. These are listed in Table 8-6.

COMPANY	PROGRAM
Alliant Techsystems	lithium ion chemistry
JPL (USC)	metallic lithium chemistry
Harwell Laboratories	lithium foil chemistry
EIC Laboratories	lithium ion chemistries

Table 8-6. Air Force Lithium R&D Projects (Phillips Laboratory)

8.3.3 Navy

Most of the batteries in use by the Navy today are active primary chemistries such as lithium/sulfur dioxide, lithium thionyl chloride, lithium sulfuryl chloride, lithium manganese dioxide, and lithium carbon monofluoride. Reserve lithium chemistry systems are limited to applications requiring extended shelf lives and immunity to environmental exposure such as munitions.

Navy battery R&D focuses on lithium, with emphasis on rechargeable, high pulsed, and thermal batteries. Lithium battery systems currently under study are:

- lithium sea water systems
- lithium thermal batteries

- lithium/ metal sulfide rechargeables
- lithium and lithium-ion/ metal oxide rechargeables
- lithium anode liquid electrolyte primary batteries

The Navy's goals for rechargeable batteries are for lithium cells to increase the energy density by 100 percent and extend the cycle life by 100 percent, and for lithium ion chemistries to maintain the energy density and extend the cycle life by 500 percent.

Special purpose reserve batteries are being developed to replace zinc/silver oxide primary batteries. Reserve lithium oxyhalide and lithium thermal batteries are considered good candidates to retrofit older magnesium/silver chloride and zinc/silver oxide batteries in a variety of missile and submersible applications and will become standard in new developments such as expendable, submersible propulsion and missile guidance and control power supplies.

The Navy is striving to use commercially available lithium batteries in the following cell sizes: 9V, AA, and 2/3 A. These cells will use (CF)x, manganese dioxide, iron disulfide, and thionyl chloride cathodes. The batteries will serve as replacements for other cells which are no longer available or have poor performance. Benefits of switching to these batteries include extended storage life and improved performance at moderately low temperature. Potential applications for these batteries are underwater mines, countermeasures for underwater mines, and diver support systems.

Lithium secondary batteries are expected to replace rechargeable zinc/silver oxide batteries used in submersible vehicles and exercise torpedoes. Specific chemistries under study are lithiated vanadium and cobalt oxide in combination with a variety of electrolytes. By 1998, the Navy hopes to have available 400 to 1,000 ampere hour cells.

The Navy is working on developing several battery chemistries that offer improved energy density or power capability, or chemistries which combine both attributes. Increased energy density is important for systems such as underwater mines, data acquisition equipment (sensors and sensor relays), and person portable equipment used by special warfare units like the Navy Seals. Chemistries with the potential of fulfilling this objective are lithium thionyl chloride, lithium carbon monofluoride, and lithium manganese chloride, as well as a variety of special purpose sea water systems.

Increased power capability is important for advanced electrical/electronic weapons and certain pulsed signaling systems such as sonar. Under study in this area are advanced electrolytic capacitors and some molten salt systems. Energy and power densities are important for underwater vehicles and missiles. Chemistries with the potential of fulfilling these objectives are advanced thermal or molten salt batteries and lithium thionyl chloride batteries. They offer greater energy and power per unit weight and volume, longer life (storage, deployment, and recharges), and safety. These include lithium sea water batteries for high and low discharge rate applications and various gas cathode configurations including lithium/air (ambient temperature) and lithium/chlorine (molten salt electrolyte).

Several companies are involved in R&D efforts in this area. Eagle Picher has developed a large 1,200 ampere hour lithium battery for a deep ocean transponder with an eight year mission life. Electrochemical Corporation has a SBIR contract sponsored by the Navy to develop a high energy long life rechargeable battery with energy densities superior to current lithium systems for use in unmanned air vehicles. Wilson Greatbach Limited is involved in another Navy sponsored SBIR program to develop high pressure tolerant lithium batteries with high energy densities capable of operating at ocean depths of 20,000 feet. Two lithium chemistries being studied are chlorinated sulfuryl chloride and carbon monofluoride.

Navy battery experts believe that the next generation of chemistries that the Navy will incorporate into their weapon systems are rechargeables and lithium ion chemistries. For the Navy, Alliant Techsystems is examining lithium rechargeable batteries, and Rayovac is investigating lithium ion chemistries.

Navy 6.2 work includes:

- rechargeable lithium batteries for underwater vehicle propulsion,
- high-power lithium oxyhalide batteries for sonobuoys,
- high-power thermal batteries for sonobuoys,
- lithium-ion rechargeable batteries, and
- improved mine batteries.

Advanced development battery systems that the Navy is working on are:

- lithium sulfur dioxide batteries for sonobuoys, target vehicles, and expendable trainers
- lead fluoroboric acid batteries for projectile fuses
- sea water batteries for countermeasures, mine countermeasures (MCM), and UUV propulsion

- thermal batteries for countermeasures, MCM, sonobuoys, missiles, and unique expendables
- lithium battery system design and safety
- non-aqueous magnesium manganese dioxide as non-lithium cost/performance alternative
- large, high-capacity, high energy density lithium thionyl chloride batteries for underwater vehicles and missiles
- advanced lithium thionyl chloride replacement for zinc mercuric oxide emergency beacon
- large 6,000+ ampere hour (AH) nickel cadmium cells to replace lead acid batteries in submarines.

Regarding Navy primary battery development, two electrochemistries under development are lithium thionyl chloride and lithium thermals. These chemistries support new, low frequency, active sonobuoys to respond to shallow water operations (in response to third world crises) and quieter submarines. These low frequency sonobuoys require higher power. At present, no commercial battery is available with power and energy densities sufficient to power these low frequency sonobuoys. The Navy also is looking to replace some of its lithium sulfur dioxide batteries with lithium thionyl chloride batteries for some applications such as mines.

Table 8-7 lists companies and their R&D initiatives in Navy primary battery development.

COMPANY	PROGRAM
SAFT America	high power thermal batteries
Yardney	high power lithium thionyl chloride sonobuoy battery

Table 8-7. Navy Primary Lithium Battery R&D Projects

Recent results show that SAFT has made significant progress towards higher voltage and longer active life than present thermal battery technology. The Yardney project demonstrated the lithium thionyl chloride technology, but is no longer being funded.

To stem the proliferation of battery chemistries and sizes in the mine and mine countermeasures community, the Navy developed a "family of standard cells" using the $Li/SOCl_2$ chemistry as a base. These four or five cells are based on commercial sizes that can be assembled

to provide batteries for the next generation of mines as well as for the eventual retrofit of current mine systems. They replace older chemistries such as cadmium or zinc mercuric oxide and magnesium manganese dioxide. EIC Laboratory and ECO Corporation are working together on a project to develop a lithium thionyl chloride battery for mines.

The Navy is collaborating with the Army to develop a reserve lithium cobalt dioxide battery for hand deployed wide area mines. They are developing procedures to synthesize a charged cobalt oxide cathode and hope that this new chemistry will be safer and more reliable than the existing thionyl chloride battery.

The Navy is also working on ARPA sponsored research dealing with flexible manufacturing and rapid prototyping of solid polymer electrolyte, rechargeable ambient temperature batteries. This battery could have potential dual use applications, especially as an alternative battery to cellular and laptop applications.

8.3.4 Department of Energy

Sandia National Laboratories (SNL) is studying lithium sulfur dioxide technology to increase the reliability and active life by working with a commercial cell and improving the design. These improvements include molybdenum terminal, TA23 glass, nickel grid in anode, stainless steel case, and connector modifications for increased rigidity.

SNL also is active in R&D efforts in lithium thionyl chloride technology. Using cells designed in-house, Sandia has fabricated prototypes and currently is transferring this technology to industry, namely Honeywell, Eagle-Picher, and Wilson Greatbach.

Eveready and Oak Ridge National Laboratory are pursuing a method for packaging rechargeable thin-film lithium batteries that are as small as shirt buttons and thinner than plastic wrap. They also have a signed CRADA with the Office of Energy Research Technology Transfer to develop a microbattery that could be fabricated directly onto a computer memory chip to preserve information in the event of a power failure.

Power Conversion Inc. has a CRADA with DOE involving a nonrechargeable lithium polymer battery.

DOE believes that intermediate term/high performance battery chemistries projected to be ready for use in electric vehicles in the mid to late 1990's include lithium metal iron sulfide and lithium metal iron disulfide. Battery chemistries that are potential candidates for the electric vehicle in 10 to 15 years are lithium polymer and metal air. The U.S. Advanced Battery Consortium has funded a number of R&D lithium based projects as possible advanced battery alternatives for the electric vehicle. These include:

- W.R. Grace and Company - lithium polymer battery
- Johnson Controls, Inc. - lithium polymer battery
- Hydro Quebec - lithium polymer battery
- SAFT America, Inc. - lithium metal disulfide battery
- Lawrence Berkeley Laboratory - lithium polymer battery research and high temperature battery testing
- Sandia National Laboratory - lithium polymer battery research and high temperature battery testing
- Argonne National Laboratory - lithium metal disulfide research and testing of high temperature batteries.

8.3.5 ARPA

The Technology Reinvestment Program's (TRP) battery work has been focused on lithium battery technology. One TRP effort involves developing a rechargeable high energy density lithium ion technology for military training missions. This technology will provide low life cycle cost, rechargeable batteries. Potential commercial uses include portable telephones and lap-top computers. Participants in this initiative are SAFT America-Valdese, FMC Corporation, Motorola, Apple Computer, North Carolina A&T University, Western Piedmont College, Army Research Laboratory, and the State of North Carolina.

A second funded TRP program is looking at rechargeable lithium solid polymer electrolyte technology for use in training missions. Participants include Lockheed, Valence Technology, and Delco Remy. Twenty prototype rechargeable lithium polymer batteries have been delivered to ARPA to be used as replacements to primary lithium batteries currently in use in night vision scopes for rifles.

Both of these projects have commercial marketplace potential for applications such as cellular telephones and laptop computers. The chemistries are the same although cell production is different.

Lockheed Missiles and Space Co. has received $3 million in TRP funding to develop, over a period of 24 months, a solid polymer rechargeable lithium battery technology for use in commercial and military applications ranging from satellites to manportable communications equipment. This battery will use a solid polymer as an electrolyte and is projected to offer higher voltages than silver zinc and nickel cadmium batteries, no potential for acid leaking, no gas build-up during battery charging, higher recharging cycles, and longer cell life. The team includes Valence Technology and General Motors Corporation.

A series of TRP rechargeable technology studies currently are under negotiation at this time. ARPA also is funding research in lithium ion and lithium solid polymer chemistries. A number of contracts currently are under negotiation in this area; three of which have already been awarded:

- Carnegie Mellon - researching new material deposition techniques for electrodes
- Birl (part of Northwestern University) - Researching polymer synthesis and materials processing for electrodes
- University of Surrey (England) - Examining polymer electrolyte development.

Two SBIR contracts in place are with Research International and EIC to develop a "battery on a chip". This entails manufacturing small integrated circuits and placing the battery in the integrated circuit package. The principal short term military application is memory protection for CMOS static random access memory in the event of primary power loss. Many critical or portable data storage and miniaturized electronic devices will benefit from the availability of these thin film batteries. Potential commercial applications of this technology are memory backup or secondary power source for personal computers, portable communications, and portable data storage systems. They also could prove useful in enhancing sensors for pollution monitoring and control systems and medical devices such as implantable drug pumps and cardiac defibrillators. Additionally, a University Research Initiative contract has been awarded with the University of Minnesota to develop new components (electrodes/polymers) for rechargeable chemistries such as lithium ion and lithium metal.

8.3.6 NASA

Among the advanced battery systems NASA has under development are lithium titanium disulfide and lithium ion. The major thrust of NASA's current primary battery technology efforts

is reducing the number of different cell chemistries now used by identifying and qualifying high performance NASA standard primary cells. Johnson Space Center has led this work, including:

- Development of internal/external short circuit protection for lithium cells - JSC contracted with Yardney Technical Products on this effort.
- Development of lithium D cells capable of meeting high rate requirements while being tolerant of electrical and thermal abuse
- Development of zinc air batteries for shuttle orbiter applications.

NASA's Jet Propulsion Laboratory (JPL) is working on developing and demonstrating ambient temperature rechargeable lithium titanium disulfide cells capable of 1,000 cycles at 50 percent depth of discharge and five year storage. They also are studying ambient temperature rechargeable lithium ion cells and ambient temperature rechargeable lithium polymeric electrolyte cells to determine ways to improve the power density of the battery and extend the cycle life. Alliant Techsystems is working in conjunction with JPL on a space flight qualification services contract for a lithium thionyl chloride battery for the Titan IV. Martin Marietta is involved in lithium battery research for the Titan IV Launch Vehicle program as well. Yardney also is working with JPL under a $500,000 SBIR contract to develop a bipolar rechargeable lithium ion battery for auxiliary power tools on the space shuttle. This battery also has the potential for other aerospace and commercial applications where high discharge rate, small size, lightweight, high energy density, and long cycle life are critical design parameters.

In addition, Wilson Greatbach Limited has a SBIR contract with NASA to develop a low temperature electrolyte to improve the performance of the lithium silver vanadium oxide system used in emergency locator transmitters and emergency position-indicating radio beacons. Other potential military and space applications of this technology are superconducting wire for the fabrication of advanced high-field magnets and solenoids, electric motor windings, superconducting rotors in electric power generators, transformers, induction energy storage systems, and SQUIBS.

8.3.7 Ballistic Missile Defense Organization (BMDO)

EIC has an SBIR contract with BMDO to develop a super high energy density lithium bromine trifluoride battery with the potential to double the highest presently available energy densities. Electrochemica Corporation also has received SBIR funding from BMDO to develop a high power density battery design for space prime power. Lithium Energy Associates has a BMDO SBIR contract to evaluate high power lithium rechargeable batteries with inorganic

electrolytes for strategic defense applications. This project could have potential for the terrestrial rail gun, laser, and similar weapon systems in addition to the space power applications. It could also have potential commercial applications such as low earth orbit satellite power, cellular radios, and implantable electromedical devices such as heart defibrillators. Wilson Greatbach Limited has SBIR funding to develop a super high energy density lithium bromine fluorate battery for potential military space applications.

8.3.8 National Science Foundation (NSF)

The NSF has sponsored the Aurora Flight Sciences Corporation, working with Harvard University, in developing a lithium battery propulsion system for the next generation of low-cost unmanned aircraft for atmospheric science research. Another NSF sponsored SBIR effort funds Covalent Associates to develop stable, non-complexing anions for rechargeable lithium batteries. Improved electrolyte stability and conductivity is needed to facilitate the development of high energy rechargeable lithium batteries.

8.3.9 Department of National Defence (DND), Canada

For high power and high density energy applications in a small size format, the only current solution for communications equipment, chemical agent monitors, ELTs, and sonobuoys are expensive primary lithium sulfur dioxide batteries that offer high energy densities, low temperature performance, and good shelf life. At present, though, high operating costs limit wider use of these batteries. R&D efforts are concentrated in resolving safety issues and reducing costs. This work is carried out at the Electrochemical Science and Technology Center (ESTCO), University of Ottawa.

DND also is studying lithium rechargeable systems, namely solid polymer battery chemistries and lithium ionic battery chemistries, as replacements for the nickel cadmium batteries they currently use. These batteries are needed to power their communications and portable equipment. They offer energy densities higher than conventional rechargeable batteries, low self discharge, and low life cycle cost. DND battery experts have stated that although rechargeable lithium batteries offer high energy densities, they have not yet matured sufficiently to be suitable for commercial and military use. DND R&D efforts in this area are focused on improving low temperature performance and improving energy density. Rechargeable lithium solid polymer electrolyte batteries (SPEs) have been identified as a promising technology for CRISAT applications. This new technology offers the potential of future low manufacturing costs. It is

environmentally benign, avoids electrolyte leakage to damage electronic components, and can fit any casing shape. SPEs can be used as a rechargeable system for training or peace time exercises or as a primary battery in an emergency or wartime situation. However, SPE conductivity is very low at room temperature, precluding its use. DND is addressing the issue of increasing conductivity at lower temperature through the use of plasticizers and the development of new polymers. The lithium polymer work is being performed by Hydro-Quebec and the lithium ion work by the National Research Council (NRC).

The NRC's Institute for Environmental Chemistry lithium ion battery research focuses on development of rechargeable lithium ion cells. NRC is providing the scientific foundation while Electrofuel Manufacturing is handling the materials and prototype manufacturing. NRC researchers consider lithium ion batteries safer than metallic lithium batteries such as lithium sulfur dioxide since they contain no metallic lithium.

Ballard, in conjunction with the CANMET/Energy, Mines and Resources Canada (EMRC), is developing a commercial transit bus powered by Ballard's Solid Polymer Fuel Cells. This program was initiated to demonstrate the capability of the fuel cell by itself as the source of motive power. The first phase involved a 32 foot bus; the second phase uses a full size (40-foot) bus. This phase seeks improvements in vehicle range by applying better hydrogen storage technologies and the use of more compact fuel cells and ancillaries.

Additionally, Ballard has a Defense Development Sharing Agreement on a four-year, $3.5 million effort sponsored by the U.S. Air Force and Industry Science and Technology Canada to develop and demonstrate a rechargeable lithium sulfur dioxide battery.

Ballard also worked with the Canadian Department of Defence to study the feasibility of operating an Air Independent Power System (AIPS) solid polymer fuel cell power plant in a submarine.

8.3.10 Commercial

8.3.10.1 Medical R&D

The first commercially successful application of lithium batteries was for implantable biomedical uses. Pacemakers, defibrillators, neurostimulators, and drug delivery systems all use lithium batteries. Lithium batteries were first proposed for use in cardiac pacemakers in 1971. The

second most widely used implantable electronic device today is the implantable defibrillator which uses lithium/silver vanadium oxide systems. Implantable neurostimulators are powered by small, prismatic lithium thionyl chloride batteries.

Several new implantable biomedical devices are currently under development including the left ventricular assist device. This device currently requires power supplied by an external battery pack. Trials have been conducted using nickel cadmium batteries, but work on lithium secondary batteries for such devices is in progress. Development is also underway on batteries for implantable hearing assist devices, gait assist devices, mechanical limbs, and artificial eyes. Lithium batteries are expected to play a key role in these devices.

Hydro Quebec is in the process of developing a 14 inch "beer can" lithium polymer cell (jelly roll configuration) that can be packaged to manufacture a two kilowatt hour battery. The goal is a 1,000 cycle battery with long shelf life and a recharge time of six to eight hours. Phase III, scheduled to begin in 1995, will entail production of a 40 kilowatt hour battery and pilot plan production. Wheelchairs are the designated preliminary test application for this battery with the hope of being able to compete with lead acid batteries in terms of cost/kilowatt hour on other major applications such as electric vehicles.

8.3.10.2 Electronic R&D

Notebook computers represent a rapidly growing market for high energy density rechargeable batteries. Almost all current portable computers use the nickel cadmium battery. However, the need for higher energy density has encouraged R&D initiatives in alternate systems. Immediate near term, next generation batteries for this application are the nickel metal hydride cell and the lithium ion cell. They offer a performance advantage over presently used nickel cadmium cells and are more environmentally acceptable. Apple is using nickel metal hydride batteries in their newest notebook computers.

Several companies are pursuing advances in lithium ion technology. Sony is the only company selling lithium ion batteries for their camcorders and currently is studying rectangular lithium ion rechargeable batteries for application in portable telephones, personal computers, and liquid crystal videos. Matsushita and Sanyo have reported increases as high as 50 percent in energy storage capacity for their lithium ion prototype over the Sony commercial product. Matsushita has begun selling two types of cylindrical lithium ion cells and one rechargeable cell and is expected to expand their production capabilities to produce one million cells per month by

the end of 1994. A joint venture of Asahi and Toshiba is reported ready to begin production of hundreds of thousands of lithium ion cells per month. Duracell, Eveready, and Rayovac and a number of European battery manufacturers also have initiated lithium ion programs focusing on the portable electronics battery market.

Regarding lithium manganese dioxide developments, Dowty Batteries has developed a lithium manganese dioxide three volt battery for applications such as heating controllers, computer memory protection, real time clocks, and data loggers. Maxell Corporation of America also is developing a new lithium manganese dioxide secondary battery for use as a memory backup power supply.

An alternative, longer term, candidate for high energy density portable power is the rechargeable lithium polymer battery. However, there are safety concerns that need to be addressed before it can be commercialized.

8.3.10.3 Electric Vehicle R&D

The U.S. Advanced Battery Consortium (ABC) is studying lithium polymer and lithium iron disulfide batteries for electric vehicles (EV). Argonne National Laboratory has developed a lithium iron sulfide battery that can be recharged 1,000 times, giving it a 100,000 mile lifetime in an electric vehicle before replacement. The battery can allow acceleration from zero to sixty miles per hour in eight seconds and provides a 300 mile range. It weighs considerably less than other EV batteries currently in use and is expected to be packaged in less than half the size of batteries previously used in electric vehicles. The battery also has potential application in airport vehicles, lift trucks, hybrid vehicles, and as standby energy storage and backup power for computer systems and telephone switching equipment. Argonne is working closely with SAFT America to commercialize the battery.

Hydro Quebec is developing secondary lithium polymer cells for a two kilowatt hour lithium polymer battery with the ultimate goal of developing a 40 kilowatt hour battery for electric vehicles. In December 1993, Hydro Quebec, in conjunction with 3M Corporation, was awarded a $32 million contract from the U.S. ABC to develop and demonstrate a 127 watt hour/kilogram lithium polymer battery.

Delco Remy, in conjunction with Valence Technology, Inc., is developing high-energy lithium polymer batteries for electric vehicles.

8.3.10.4 Utilities R&D

Power Conversion Inc. is developing a long shelf life utility meter battery that is activated for short, few second intervals every month to obtain a reading of the usage for that period. They are exploring the possibility of attaching a lithium passive layer to the battery to achieve this.

Tables 8-8 through 8-12 list North American and foreign players in the lithium R&D effort.

INDUSTRY		
Advanced Energy Technologies, Inc.	EIC Laboratories	Panasonic
Advanced Technology and Research, Inc.	Electrochemica Corporation	PolyPlus Battery Company
Alliant Techsystems Inc.	Electrofuel	Power Conversion Inc.
Applied Power International	Energy Conversion	Ray-O-Vac
ARCO Medical	Eveready	SAFT - America
Arthur D. Little, Inc.	GE Neutron Devices	Sony
ATT Bell Laboratories	General Dynamics Space Systems	Sharp
Aurora Flight Sciences Corporation	General Motors	SRI International
Ballard	Gould Inc.	Technochem
Battery Engineering Inc.	HED Battery Corporation	The Aerospace Corporation
Bellcore	HEDB Corporation	Ultralife Technologies
Bell Labs	Hoppecke Battery Systems, Inc.	U.S. Advanced Battery Consortium
Catalyst Research	Johnson Controls	UCAR Caron Company
Coastal Systems Station	Lithium Energy Associates	Valence Technology
Covalent Associates	Martin Marietta Aerospace	Westinghouse Electric Corporation

Table 8-8. North American Industry Lithium R&D Players

INDUSTRY		
Dowty Batteries	Maxell Corporation of America	Wilson Greatbach Limited
Delco Remy	Medtronics Inc.	W. R. Grace
Duracell Inc.	Microchip Technology Inc.	Yardney Technical Products
Eagle-Picher Industries	Mine Safety Appliances Company	
ECO Energy Conversion	Moli Energy	

Table 8-8, Cont. North American Industry Lithium R&D Players

LABORATORIES	UNIVERSITIES
Air Force Wright Aeronautical Laboratory	California Institute of Technology
	Harvard University
Army Research Laboratories	Jet Propulsion Laboratory
Argonne National Laboratories	Polytechnic University
Bell Labs	Texas A&M University
George C. Marshall Space Flight Center Naval Surface Warfare Center	University of Dayton Research Institute
Hydro Quebec	University of Kentucky
Jet Propulsion Laboratory	University of Minnesota
Lawrence Berkeley Laboratory	University of Pennsylvania

Table 8-9. North American Laboratory and University Lithium R&D Players

[illegible]	[illegible]
National Research Council, Canada	University of Texas
Naval Surface Warfare Center - Crane	University of Texas at Austin
Naval Surface Warfare Center - White Oak	University of Waterloo
Naval Weapons Support Center	University of Ottawa
Oak Ridge National Laboratory	
Sandia National Laboratories	
U.S. Air Force Space and Missile Center	
U.S. Army ETDL	
Wright Laboratory	
Wright Patterson Air Force Base	

Table 8-9, Cont. North American Laboratory and University Lithium R&D Players

COUNTRY	COMPANY	CHEMISTRY
United Kingdom	AEA	rechargeable lithium batteries
	SAFT NIFE	lithium ion secondary, lithium thionyl chloride
	Dowty Batteries	lithium manganese dioxide batteries
	Dorutcy	
	British ARE	lithium iron sulfides
	Oakdale Batteries	lithium aluminum iron sulfide secondary battery for submarines
	Vickers	lithium iron sulfides
	VSEL	lithium aluminum iron sulfide secondary battery for submarines
Germany	Varta AG	lithium polymer secondary, lithium thermal
	BAFF	
	Bayer Fulrik	
	Hoppecke Batterien	lithium primary batteries
	Siemens	
Israel	Tadiran	lithium ion
	Israel Defense Forces Power Sources Division	
Belgium	SEDEMA	rechargeable lithium cells
Switzerland	RENATA	secondary lithium batteries

Table 8-10. Foreign Industry Lithium R&D Players

<table>
<tr><th>COUNTRY</th><th>COMPANY</th><th>CHEMISTRY</th></tr>
<tr><td rowspan="12">Japan</td><td>Central Glass Company Ltd.</td><td rowspan="2">lithium ion secondary, lithium polymer, and lithium iron sulfide</td></tr>
<tr><td>Sony</td></tr>
<tr><td>Toshiba Asahi Chemical Joint Venture</td><td rowspan="9">lithium ion cells</td></tr>
<tr><td>Hitachi</td></tr>
<tr><td>Sanyo</td></tr>
<tr><td>Toshiba</td></tr>
<tr><td>Asahi</td></tr>
<tr><td>Yuasa</td></tr>
<tr><td>Matsushita</td></tr>
<tr><td>Mitsubishi Petrochemical Company</td></tr>
<tr><td>Sharp</td></tr>
<tr><td>Honda Research and Development Corporation</td><td>lithium ion technology</td></tr>
<tr><td rowspan="3">France</td><td>SAFT</td><td rowspan="2">lithium ion secondary, lithium polymer, lithium thionyl chloride, lithium thermal, lithium vanadium pentoxide</td></tr>
<tr><td>Alcatel</td></tr>
<tr><td>INSA</td><td>rechargeable lithium cells</td></tr>
</table>

Table 8-10, Cont. Foreign Industry Lithium R&D Players

COUNTRY	UNIVERSITY
Bulgaria	Bulgarian Academy of Sciences
China	Beijing Institute of Spacecraft System Engineering
	Changchun Institute of Applied Chemistry
	Chinese Academy of Sciences
	Tianjin Institute of Power Sources
	Institute of Physics, Academia Sinica
	Tianjin University, Department of Applied Chemistry
Czech Republic	Wuhan University
Denmark	Technical University of Denmark
France	CNRS - FranceCzech Academy of Sciences
	SORAPEC
	Universite Bordeaux
Germany	Dresden University of Technology, Institute of Physical Chemistry and Electrochemistry
	Ernst-Moritz-Arndt University of Greifswald
	Fraunhofer-Institute for Chemical Technology
	Merseburg University, Institute of Macromolecular Chemistry
	University of Munster
Greece	Aristotelian University
	University of Ulm
Israel	Bar-Ilan
	Tel Aviv University
Italy	Universita di Bologna

Table 8-11. Foreign Universities Lithium R&D Players

COUNTRY	UNIVERSITY
Japan	Chubu University
	Iwate University
	Keio University
	Kyoto University
	Mie University Rikkyo University
	NTT Interdisciplinary Research Laboratories
	Shinshu University Tokyo Institute of Technology
	Yamaguchi University
Netherlands	Delft University of Technology
Poland	Central Laboratory of Batteries and Cells
	Technical University of Poznan, Institute of Chemistry and Applied Electrochemistry
	University of Warsaw
	Warsaw University of Technology
Russia	A.N. Frumkin Institute of Electrochemistry of the Russian Academy of Sciences
	Frumkin Institute of Electrochemistry
	Institute of Chemical Engineering
	Institute of Transportation Engineering
	Russian Academy of Sciences
	Saratov State University
	University of St. Andrews
Scotland	National Institute of Chemistry
Slovenia	National Central University
Taiwan	Chung Shan Institute of Science and Technology

Table 8-11, Cont. Foreign Universities Lithium R&D Players

COUNTRY	LABORATORY
Australia	Australian Army Engineering Development Establishment
France	Laboratoire d'Ionique et d'Electrochimie du Solide, Institute National Polytechnique de Grenoble
	Laboratoire de Chimie du Solide Mineral

Table 8-12. Foreign Laboratories Lithium R&D Players

8.4 Mercury

This chemistry will disappear soon from the domestic marketplace. As legacy systems and old Navy mines are replaced, the mercury batteries that support these systems also will be replaced. There is only one North American producer of mercury batteries, Alexander Batteries. Alexander Batteries is concerned about future defense procurements of mercury batteries and has explored the possibility of becoming a government-owned, contractor-operated facility. The only other mercury battery producer is located in Hong Kong.

8.4.1 Army

The Army believes that mercury is no longer suitable for Army requirements. Mercury batteries are environmentally expensive, both in their manufacture and disposal, and have performed poorly in terms of low temperature operation, shelf life, and weight. Among the alternatives being considered to replace mercury batteries are alkaline and lithium manganese dioxide chemistries.

8.4.2 Navy

The Navy still installs mercury batteries in mines but is attempting to replace most mercury batteries in its fleet with suitable substitutes due to environmental considerations and the dwindling availability of this battery type in the marketplace.

8.5 Silver Systems

Efforts are underway to improve the properties of secondary silver zinc batteries and allow longer service life and higher energy density. The silver cadmium battery is experiencing no technological advancement. The silver cadmium system, which is used primarily in satellites, torpedoes, and portable power tools, will probably be phased out in most applications in the future due to environmental considerations.

8.5.1 Navy

The Navy is studying ways to develop an improved rechargeable silver zinc battery. The silver oxide/zinc battery is the Navy's power supply for several underwater vehicles including Swimmer Delivery Vehicles, Deep Submergence Rescue Vehicles, deep sea vehicles, exploratory vehicles, unmanned underwater vehicles, torpedoes, and torpedo targets. These batteries offer the highest energy density of any commercially available, high power rechargeable battery. However, they have limited capacity, deteriorate after 3 to 18 months, and can only be recharged 40 times. The Navy needs a battery that offers a higher energy density to power longer run times of future vehicles. They are exploring ways to increase the energy density by 50 percent and extend cell life by 50 percent. Yardney has been awarded approximately $500,000 from Naval Surface Warfare Center - White Oak for a two year program to change the electrolyte and separator to improve the properties of secondary silver zinc batteries. Improvements sought include cycle life, wet life, and energy density. Also involved in contractual efforts in this area are BST, Eagle Picher, and Whittaker Power Sources, though Whittaker's focus has been primarily on missile batteries.

8.5.2 NASA

NASA's Jet Propulsion Laboratory is currently examining a 40 ampere hour silver zinc secondary battery to power the Mars Pathfinder. This battery will need to sustain cruise power and operate for 30 days on the Martian surface. The Mars Pathfinder is scheduled for launch in 1996.

8.5.3 Commercial

8.5.3.1 Medical

Silver zinc batteries are being studied for their potential in such medical systems as advanced CPR units. Commercial producers feel that the safety, reliability, and high power of the

silver zinc batteries justify the cost premium in these specialized applications. Table 8-13 lists North American industry, laboratories, and universities involved in silver battery R&D efforts.

INDUSTRY	LABORATORIES	UNIVERSITIES
BST Systems, Inc.	Argonne National Laboratory	Auburn University
Eagle Picher Industries Inc.	Brookhaven National Lab	Harvard
Electrochemica	Charles Stark Draper Lab	New Mexico State University
Energy Research Corporation	George C. Marshall Space Flight Center	Pennsylvania State University
Hughes	Lawrence Berkeley Laboratory	Rutgers
McDonnell Douglas Space Systems Corporation	NASA Goddard Space Flight Center	University of Alabama
SAFT-America	NASA Jet Propulsion Laboratory	University of Houston
Westinghouse Electric Corp.	NASA Johnson Space Center	
Whittaker Power Storage Systems	NASA Lewis Research Center	
Yardney Technical Products Inc.	NASA Marshall Space Flight Center	
	Naval Surface Warfare Center (NSWC), Crane	
	NSWC, Silver Spring	
	Sandia National Laboratory	
	U.S. Army ETDL	
	Wright Patterson Air Force Base, Wright Laboratory	

Table 8-13. North American Silver Battery R&D Players

8.6 Lead Acid

The development of sealed valve regulated lead acid (VRLA) batteries has been a decisive improvement on this century old technology. Most lead acid battery applications today employ the

sealed version of this battery. In the 25 years since their introduction, VRLA batteries have become either the only type or most dominant type of lead acid battery used in many applications. These batteries, under normal conditions, operate throughout their lives without water addition. The inherent design of VRLA batteries allows different orientations of the battery without fear of electrolyte spillage. For example, large industrial batteries can be installed on their sides utilizing 40% less floor space and volume.

Areas of improvement are increasing VRLA batteries' energy density, recharge time, and cycle life in advanced designs. R&D activities for military applications focus on the following areas: improved low temperature performance, especially recharge time; increased vibration resistance; increased shelf life/storage capability; high temperature performance and charging capability (up to 75° C); and reduced self discharge at temperatures up to 75° C. Strides in these areas are driven by the battery industry's goal to capitalize on two emerging markets: Electric Vehicles (EV's) and Utility Energy Storage Applications.

8.6.1 Air Force

The Air Force has contracted with Johnson Controls, Inc. to design, develop, and demonstrate a bipolar lead acid battery system compatible with the 270V aircraft electrical system requirements. This program is scheduled to be completed in September of 1995.

8.6.2 Navy

The Navy currently is examining lead acid batteries and lead fluoroboric acid batteries for ways to extend useful life, decrease the level of maintenance, and allow greater standardization of the batteries which the Navy uses. Major applications of the lead acid batteries are in submarines and aircraft. Fluoroboric acid batteries are used primarily in projectile fuses.

8.6.3 Department of Energy (DOE)

The DOE considers the lead acid chemistry a likely battery for electric vehicles in the near term and research is continuing to adapt these systems.

8.6.4 Ballistic Missile Defense Organization (BMDO)

Johnson Controls Inc. has the largest lead acid research facility in the U.S. They have developed an advanced lead acid bipolar battery for BMDO that produces bursts of high power for a few seconds and recharges up to 100 times. BMDO sponsored this research for advanced railgun and laser applications. A new generation of their bipolar devices is expected in September of 1994.

8.6.5 Industry

8.6.5.1 Electric Vehicles

The Advanced Lead Acid Battery Consortium believes that lead acid batteries are the best alternative for powering near term electric vehicles. Table 8-14 below lists lead acid batteries used in electric vehicles R&D programs.

VEHICLE	BATTERY
Fiat's Panda Elettra	uses lead acid batteries which can be replaced with nickel cadmium or sodium sulfur battery packs
Fiat's Cinquecento Elettra	uses lead acid batteries for a 70 km range and nickel cadmium batteries for the 100 km range
Fiat's and Peugeot-Citroen's Ducato Elletra	uses lead acid batteries
CAT's CleanAir LA 301	uses lead acid batteries
General Motors Impact	uses lead acid batteries
Conceptor's G-Van	uses lead acid batteries
Daihatsu's Hi-Jet	uses lead acid batteries
SEER's Volta	uses lead acid batteries
CityCom's Mini-el City	uses lead acid batteries
Toyota Motor Company's Town Ace	uses lead acid batteries
Mitsubishi's Libero	uses lead acid or nickel cadmium batteries
Elcat"s Elcat	uses lead acid batteries

Table 8-14. Lead Acid Batteries Used in Electric Vehicles

Electronic Power Technology Inc. has developed the technology to significantly shorten the recharging time for lead-acid batteries used in an electric vehicle.

8.6.5.2 Power Tools

Johnson Controls' new lead acid bipolar battery also could power spot welders. Bolder Technologies Corporation is concentrating on a Thin Metal Film advanced lead acid rechargeable battery for use in power tools, uninterruptible power systems, consumer electronics, and other applications that require high power, fast recharge, stiff voltage, and exceptional high-rate capacity. Portable Energy Products also has developed advanced rechargeable sealed lead acid Thin Line Energy cells.

Tables 8-15, 8-16, 8-17, and 8-18 list North American and foreign players in lead acid battery R&D efforts.

LABORATORIES	UNIVERSITIES
Argonne National Laboratory	Auburn University
Idaho National Engineering Laboratory	Brigham Young University
Jet Propulsion Laboratory, NASA	Dartmouth University
Naval Surface Warfare Center, Crane	University of Idaho
Sandia National Laboratory	Northwestern University
Wright Patterson Air Force Base Laboratory	Rutgers University
Bellcore Communications Research	University of Alabama
	University of Michigan
	Stanford University
	Texas A&M University
	University of Wisconsin

Table 8-15. North American Laboratory and University Lead Acid R&D Players

INDUSTRY		
Acme Battery Manufacturing Co.	Concorde Battery	GNB Battery Technologies
Arias Associates	Delco	Johnson Controls Inc.
Amerigon, Inc.	Douglas Battery Manufacturing Company	Norvik Technologies, Inc.
Battelle	East-Penn Manufacturing Company	Portable Energy Products
Bolder Technologies Corporation	Eagle Picher Industries	Trojan Battery Company
C&D Charter Power Systems	Electronic Power Technology Inc.	Tulip Corporation
CALSTART	Electrosource Inc.	Wirtz Manufacturing Co. Inc.
Chloride Industrial Batteries	Exide Corporation	Yuasa Exide
Cominco	Gates Energy Products	

Table 8-16. North American Industry Lead Acid R&D Players

COUNTRY	INDUSTRY
Australia	Pacific Dunlop, Ltd.
England	CMP Batteries, Ltd.
	ERA Technology
Europe	Advanced Lead Acid Battery
France	Compagnie Europeenne D/Accumulators
Germany	VARTA Batterie AG

Table 8-17. Foreign Industry Lead Acid R&D Players

COUNTRY	INDUSTRY
Japan	Japan Storage Battery
	Kashimma-Kita Electric Power
	Mitsubishi Petrochemical Company
	Yuasa Battery Co. Ltd.
Korea	Kyungwon Battery Co. Ltd.
Turkey	Inci Aku
UK	Hawker Energy Products

Table 8-17, Cont. Foreign Industry Lead Acid R&D Players

COUNTRY	LABORATORIES	UNIVERSITIES
Australia	CSIRO Laboratories	University of South Wales
England		University of South Hampton

Table 8-18. Foreign Laboratory and University Lead Acid R&D Players

8.7 Nickel Systems

R&D efforts are ongoing to improve the properties and extend the life of nickel cadmium batteries. The future trend is to transition from vented nickel cadmium aircraft batteries into sealed nickel cadmium batteries.

Nickel hydrogen batteries have become the battery of choice for applications such as commercial and defense-related satellites in geosynchronous and low earth orbits. The technology also has become attractive recently for use in ground-based applications such as stand-alone photovoltaic systems.

Many battery experts feel that, in the long term, the trend will be to move away from nickel cadmium and nickel hydrogen cells for many applications and toward nickel metal hydride cells. A market for this chemistry is evolving in the small portable electronics industry. However, these batteries are not yet available except in small sizes at high cost.

8.7.1 Army

In the rechargeable area, the Army currently is using nickel cadmium batteries. The present version weighs approximately seven pounds and does not supply power for the desired duration. They are looking to adopt a commercially available advanced nickel cadmium or nickel metal hydride battery as a replacement in the short term and move towards a lithium ion or polymer battery in the long term.

Other initiatives include phasing out nickel cadmium aircraft batteries and improving discharge rate capabilities of the nickel metal hydride cells for the tank "silent watch" and hybrid/electric Army vehicles. They are also considering nickel zinc chemistries as possible future rechargeable batteries.

8.7.2 Air Force

The Air Force prefers nickel cadmium batteries to lead acid and is replacing lead acid batteries in some aircraft with sealed nickel cadmium batteries. Eagle-Picher is working on qualifying a sealed nickel cadmium battery for vented nickel cadmium retrofit on the B52 aircraft. This action will generate a savings of approximately $3,000 per year per aircraft which is presently spent on aircraft battery maintenance. Retrofitting with maintenance-free, sealed nickel cadmium battery systems in place of vented nickel cadmium systems is expected to begin by the end of 1994 in F-16 fighters and in the E-8 advanced AWACS aircraft. Sealed nickel cadmium batteries offer advantages of reduced maintenance (and thus reduced operating cost) by eliminating the process of adding electrolyte to the battery. The commercial aviation industry has employed sealed nickel cadmium batteries, in small quantities, on the MD-80 and DC-9 aircraft. These same batteries are expected to be used on the MD-90 and the Boeing 777 aircraft. Eagle-Picher Industries in

conjunction with ELDEC currently is pursuing research to develop a nickel cadmium battery that will have zero maintenance and last 20 years. The scheduled completion date of this Air Force contract is March of 1995.

The Air Force and Navy jointly contracted with Battelle to develop a common 15 ampere hour INS Battery specification utilizing High Reliability Maintenance Free Battery Technology. Phase II of this effort involved designing and building common (Air Force and Navy) 15 ampere-hour batteries for flight testing. Both sealed nickel cadmium batteries and lead acid batteries were considered in the technology and comparison process. This initiative is helping the two services reduce maintenance costs associated with these batteries

The use of nickel cadmium batteries is likely to be affected greatly by the environmental concerns of handling and disposal of heavy metals. The Air Force looks to nickel metal hydride batteries as replacements for nickel cadmium batteries. Nickel metal hydride batteries offer a 50 percent increase in energy content per volume over nickel cadmium batteries, offer significant operating cost benefits over primary batteries, utilize no toxic heavy metals, have a commercial market, and are a relatively safe technology. They feel that this technology will emerge in five years. Electro Energy, Inc. is working with Wright-Patterson to develop these nickel metal hydride batteries for aircraft and ground power. The expected completion date for this project is September of 1995.

U.S. Air Force Phillips Laboratory is conducting R&D on the nickel metal hydride chemistry. Programs include an LEO Life Test Program, an LEO pulse Tech Program, and a Hydrogen Embrittlement Investigation Program.

Wright Patterson has contracted with Energy Research Corporation to develop long cycle life, insoluble zinc electrodes that will be utilized in zinc batteries. The anticipated benefits are long life, high energy density nickel zinc batteries for commercial, military hybrid, and all-electric vehicles, marine propulsion, and remote site power.

8.7.3 Navy

The Navy currently is exploring ways to improve nickel cadmium systems including improving the electrodes, prolonging useful life, and achieving higher energy densities. These batteries are used in submarines and other vehicles. They also are investigating the potential of nickel hydrogen and nickel metal hydride chemistries.

The Navy SHARP program identified the problem of different batteries for Inertial Navigation System on large cargo and special application aircraft. It was determined that the battery used in the Navy LTN-72 and Air Force Delco Carousel 4 Inertial Navigation Systems (INS) could be replaced with the same high reliability, maintenance free, battery technology. These batteries currently are used in up to 3,500 INS aircraft, and the replacement battery will require no scheduled maintenance services for the expected five year service life.

8.7.4 NASA

NASA's major emphasis is on secondary battery systems and verifying technologies for flight applications. One initiative is to improve the performance, quality, safety, and reliability of secondary battery systems. The focus at present is on nickel cadmium and nickel hydrogen systems which encompass most of NASA's present and planned secondary battery applications. Nickel cadmium batteries currently provide the storage capability for the majority of NASA's missions. Evaluation is underway of current technology nickel cadmium cells from a variety of battery producers including Gates, Hughes, SAFT, Sanyo, Acme, and Eagle Picher. Nickel hydrogen batteries being tested have been supplied by Hughes, Eagle Picher, Gates, and Yardney. Stress testing of packs of cells representing the flight lots and mission simulation testing of cells for the Mars Observer and Topex also are ongoing.

NASA's Jet Propulsion Laboratory (JPL) currently is developing nickel cadmium cell battery flight simulation and stress testing and, based upon these principles, a nickel cadmium performance/prediction model.

Nickel hydrogen batteries are the primary rechargeable technology found in satellites and are used in the majority of space applications including the Hubble Space Telescope and the Intelsat 8 communications satellite. Sandia Labs has sponsored R&D for developing a safe and practical method of hydrogen retention for nickel hydrogen batteries and improving the active anode area. These efforts will reduce by half the cost of nickel hydrogen batteries for terrestrial applications.

In response to more demanding space power needs, NASA would like a lightweight long life battery for its high power spacecraft and currently is examining an improved nickel metal hydride battery with improved specific energy. NASA Lewis' efforts are focused on developing lightweight nickel hydrogen batteries and advanced hydrogen oxygen fuel cells. They developed the nickel hydrogen battery cells powering the Hubble Space Telescope and currently support R&D

of battery cells for the Space Station Freedom Program. Johnson Controls, Inc. is developing full-size, aerospace common pressure vessel nickel hydrogen prototypes for use on GEO and LEO applications. Hughes Aircraft Company is also investigating a nickel hydrogen battery for space power.

JPL currently is developing an electrochemical model of the nickel cadmium system that involves physical, chemical, and electrochemical studies at the component and cell levels. This model will allow accelerated testing of cells to determine their quality and reliability without extensive life testing and the ability to predict their performance from a set of spacecraft operating conditions. This effort is expected to be completed by the end of FY94 and has involved the following phases:

- Phase I - Lookup table for predicting performance/voltage and efficiency versus temperature and state-of-charge
- Phase II - Development of one dimensional electrochemical model to replace lookup tables (developed under a contract with Texas A&M)
- Phase III - Expansion to a two dimensional model, incorporating factors to predict performance degradation.

JPL is developing with the University of South Carolina a computer model for nickel hydrogen batteries that will parallel the model they developed for the nickel cadmium system. They also are assessing the status of nickel metal hydride technology for aerospace applications by evaluating aerospace cells from different sources.

The Marshall Space Flight Center is developing a nickel hydrogen stress test similar to the test currently used for nickel cadmium cells. Available life test data is being analyzed, stress parameters have been identified, and a matrix has been proposed. The Flight Center is also addressing establishment of guidelines for NASA for the performance of destructive physical analyses for nickel cadmium and nickel hydrogen chemistries.

Among the advanced battery systems NASA has under development are nickel metal hydride and sodium nickel chloride.

8.7.5 Department of Energy (DOE)

In the near term, DOE believes battery chemistries likely to be used for electric vehicles include nickel iron, nickel cadmium, and nickel zinc. Nickel metal hydride batteries are projected

for intermediate term use (mid to late 1990's) in electric vehicles. The U.S. Advanced Battery Consortium (ABC) has awarded a number of contracts dealing with advanced battery systems for the electric vehicle. Nickel based programs include:

- Ovonic Battery Company - nickel metal hydride battery
- SAFT America - nickel metal hydride battery
- Idaho National Engineering Laboratory - testing of nickel metal hydride and high temperature battery packs.
- Argonne National Laboratory - testing of nickel metal hydride and high temperature batteries.

The USABC is also examining nickel hydride batteries for electric vehicles. Argonne National Laboratory is testing advanced nickel metal hydride and sodium beta high temperature for USABC.

DOE conducted research on three propulsion systems. One system was a dual shaft electric propulsion system. This research was completed in 1989 and featured a nickel iron battery. A sealed lead acid battery will be installed for further testing at a later date.

Table 8-19 lists electric vehicles that are currently using or projected to use nickel cadmium batteries.

[illegible]	[illegible]
Fiat's Panda Elettra	uses lead acid batteries which can be replaced with nickel cadmium or sodium sulfur battery packs
Volkswagen's Chico	uses nickel cadmium batteries
Nissan's prototype Future Electric Vehicle	uses nickel cadmium batteries
PSA's CITELA	uses nickel cadmium batteries

Table 8-19. Nickel Cadmium Batteries in Electric Vehicle R&D Programs

VEHICLE	BATTERY
Nissan's Cedric/Gloria electric luxury sedan	uses nickel cadmium batteries
The Tokyo Electric Power Company and Mitsubishi Motors Electric Vehicles	uses nickel-cadmium batteries
Peugeot's 106E	uses nickel cadmium batteries

Table 8-19, Cont. Nickel Cadmium Batteries in Electric Vehicle R&D Programs

8.7.6 Ballistic Missile Defense Organization (BMDO)

EIC Laboratories has SBIR funding sponsored by the BMDO to develop a nickel oxide/hydrogen multilayer bipolar battery for pulsed power. These batteries will be used to operate directed energy weapons in space-based missile defense systems.

8.7.7 Industry

8.7.7.1 Aerospace

ACME Advanced Battery Systems has developed new, sealed technology fiber nickel cadmium batteries for aircraft. This technology is already in use on some of the McDonnell Douglas MD-80 and DC-9 commercial transports, the F-16 fighters, and Apache helicopters and is projected for use on the MD-90 and the Boeing 777 aircraft.

Rockwell International is developing nickel cadmium space vehicle batteries in support of the Global Positioning System program. They are considering the nickel metal hydride battery for aerospace applications as well.

Eagle Picher presently provides 90 percent of the world's communications satellite nickel hydrogen batteries. The company has developed a prototype of a small, low-cost nickel metal hydride battery in capacities of 20 amp-hours or less with a common pressure vessel design for small satellites and commercial uses requiring low cost batteries. Eagle Picher also has introduced a commercial nickel hydrogen battery for uninterruptible power systems.

8.7.7.2 Electric Vehicles

Japan Storage Battery Company has developed a prototype gas recombinate sealed nickel cadmium battery with an improved negative electrode for possible use in electric vehicles. Eagle Picher is currently working on nickel metal hydride batteries for electric vehicles and embedded, maintenance-free telecommunications power systems.

8.7.7.3 Electronic Applications

Apple Computer currently is investigating a nickel metal hydride battery with an AB5 hydrogen retaining alloy for its next notebook computer model. Duracell, in conjunction with VARTA (Germany) and Toshiba (Japan), is developing nickel metal hydride rechargeable cells and packs for, among other applications, portable products such as notebook computers, cellular phones, camcorders, and personal digital assistants.

Tables 8-20 thru 8-23 list North American and foreign players in nickel chemistry R&D.

INDUSTRY	LABORATORIES
ACME Advanced Battery Systems	EIC Laboratory
ATT Bell Laboratory	George C. Marshall Space Flight Center
Battelle	NASA-Goddard
Eagle-Picher Industries	NASA-Jet Propulsion Laboratory
Energy Research Corporation	NASA-Lewis
Eveready Battery Company	Naval Surface Warfare Center, White Oak
Foster Miller Incorporated	Naval Surface Warfare Center, Crane
Hughes Aircraft Company	Wright Patterson Air Force Base
Rockwell International	U.S. Army Research Laboratory
Marathon Power Technologies	
SAFT America, Inc. (Valdosta)	
The Aerospace Corporation	

Table 8-20. North American Nickel Cadmium R&D Players

INDUSTRY	LABORATORIES	UNIVERSITIES
Comsat Corporation	Naval Weapons Support Center	Crowder College
Eagle-Picher Industries	NASA Lewis	Texas A&M University
EIC Laboratories	NASA Marshall	
Gates Energy Products	U.S. Air Force Phillips Lab	
Hughes Aircraft Company		
Johnson Controls, Inc.		
Lockheed Missiles and Space Company		
Yardney		

Table 8-21. North American Nickel Hydrogen R&D Players

INDUSTRY	LABORATORIES	UNIVERSITIES
Apple Computer	Argonne National Laboratory	Rutgers University
Comsat Corporation	Idaho National Laboratory	Texas A&M University
Duracell	NASA Johnson Space Center	Texas Research Institute
Eagle-Picher Industries	NASA Lewis Research Center	University of Alabama in Huntsville
Electro-Energy, Inc.	Wright Patterson Air Force Base	
Eveready Battery Company		
Lockheed Engineering and Sciences Company		
Maxell Corporation of America		
Ovonic Battery Company		
Rockwell International		
The Aerospace Corporation		

Table 8-22. North American Nickel Metal Hydride R&D Players

COUNTRY	INDUSTRY
Germany	Varta AG
	BAFF
	Bayer Fulrik
	Siemens
Japan	Matsushita
	Sanyo
	Toshiba
	Yuasa Battery Company
France	Aerospatiale
	Alcatel
	SAFT

Table 8-23. Foreign Nickel Metal Hydride R&D Players

8.8 Magnesium

This chemistry is not undergoing any major technological changes. Military manufacturing of this battery is primarily for the Navy CAPTOR mine. The production of this battery uses a very antiquated low tech process and is labor intensive. This chemistry is very similar to the commercial alkaline chemistry and most likely will be replaced in the future by longer lasting primary systems.

8.8.1 Army

The Army uses a commercially available version of this chemistry that is mass produced by Rayovac. The Army uses the battery in their manportable equipment for training exercises, but the batteries have temperature range limitations.

Faced with budget cuts, the Army is interested in reducing battery training costs. They contracted with Rayovac to develop prototype BA 4590 magnesium manganese dioxide batteries incorporating barium chromates as possible replacements for the BA 5590 lithium battery. Overall, the prototype did not perform well at extreme conditions. The battery dimensions were not stable,

and the external temperatures exceeded 45 degrees Celsius at certain conditions. The lithium BA-5590/U performance was far superior. SINCGARS simulation tests showed that only at elevated temperatures are the magnesium BA-4590 batteries cost effective versus lithium BA 5590/U. Rayovac will deliver the last prototypes to CECOM/ARL in December of 1994. CECOM/ARL will then test these for the next year or so, but the technology is not considered feasible. An additional consideration for not using this battery chemistry is that the EPA has become concerned with the environmental impact of the chromates used in these cells.

8.8.2 Navy

The Navy is interested in prototype and advanced development of its magnesium sea water systems, particularly with respect to the magnesium silver chloride chemistry. These systems are used for sonobuoys, beacons, countermeasures, and some weapons. Most sea water batteries have good dry storage life but relatively short wet lives due to corrosion. Chemtech Systems, Inc. has Navy sponsored SBIR funding to develop a magnesium dioxide non-aqueous battery for mines. At this time the technology has been demonstrated and appears feasible, but no significant funding is being inserted into the program.

Tables 8-24 and 8-25 list North American and foreign players in magnesium chemistry R&D.

INDUSTRY	LABORATORIES
Battery Technologies, Inc.	Army Research Laboratory Electronics and Power Sources Directorate
Chemtech Systems, Inc.	Naval Weapons Support Center
Magnavox	
Rayovac	
Spartan	

Table 8-24. North American Magnesium R&D Players

COUNTRY	INDUSTRY	UNIVERSITY
Holland	Phillips Electronics NV	
India		Central Electrochemical Research Institute
Japan	Matsushita Electric Industries Company	

Table 8-25. Foreign Magnesium R&D Players

8.9 Zinc systems

Zinc battery systems do not satisfy a large number of applications; rather they have existed as a lower cost alternative battery with acceptable performance. Some chemical configurations are being phased out while other configurations are being considered for future applications.

8.9.1 Army

The Army is phasing out their carbon zinc batteries. Problems associated with carbon zinc batteries are poor shelf life, low capacity, and poor low temperature performance. Some carbon zinc cells are no longer produced. The Army is examining the potential for replacing these batteries with alkaline batteries. These replacements would have not only improved capacity but also the same envelope and connector requirements.

8.9.2 Navy

The Navy currently is studying off-the-shelf, commercially available zinc alkaline manganese dioxide batteries as potential batteries for future use in applications where availability and cost are important and "reasonable" performance is needed. The cell would be a commercially available product; however, it would be packaged uniquely for the Navy's requirements. The Naval Surface Warfare Center, Crane and White Oak Divisions, are conducting product evaluations of cells of this chemistry.

8.9.3 DOE

The DOE considers zinc bromine and nickel zinc chemistries as near term contenders for electric vehicle batteries. Significant advances in Zn/NiOOH cell technology have been made, and scale-up/technology transfer is underway. Westinghouse Electric Corporation is supporting DOE in advancing zinc air technology by developing a prototype design of an electric vehicle battery and fabricating battery modules for proof-of-concept evaluations.

8.10 Aluminum-Air

The aluminum air chemistry currently has few military applications. It is used primarily to power propulsion of unmanned, underwater vehicles. The Canadian military is the only military buyer of these batteries. Commercial applications for non-rechargeable aluminum air batteries are telecommunications, standby, and emergency power.

8.10.1 Industry

Alupower, a Canadian firm that concentrates on aluminum air batteries, is developing an aluminum-based battery for unmanned, underwater vehicles. The battery will be used to power propulsion and navigation. Customers include Canadian DND, ISTC, and MNR; the Ontario Ministry of Environment and Energy; ARPA; and commercial customers such as Ontario Hydro, Bell Canada, AT&T, British and French Telecom, Renault, and Nissan.

8.11 Sodium/Sulfur Batteries

Both NASA and the Air Force are looking to transition to the sodium sulfur chemistry as their next generation battery for space and satellite applications. Industry currently is considering its potential for electric vehicles and stationary energy storage at electric utilities. This chemistry is now in the test and evaluation stage of development. Commercial production is projected for the late 1990s.

8.11.1 Air Force

Wright Patterson Air Force Aeronautical Laboratory is researching the sodium sulfur chemistry as a possible satellite battery. Thermacore, Inc. has an Air Force sponsored, SBIR funded research contract to determine interchangeable variable conductance heat pipes for sodium

sulfur batteries. These batteries are being assessed as candidates for energy storage in satellites. Eagle Picher also is under contract to design, develop, fabricate, and test sodium sulfur cells for LEO applications.

8.11.2 DOE

DOE considers sodium sulfur and sodium metal chloride chemistries as potential intermediate (mid to late 1990s) batteries for the electric vehicle. DOE is conducting research on three propulsion systems. One of these systems, demonstrated in 1990, is an advanced single shaft AC system and featured a sodium sulfur battery. The USABC has provided Silent Power with $12.1 million in funding to develop further a sodium sulfur battery for the electric vehicle. Table 8-26 lists sodium sulfur batteries currently used or projected for use in electric vehicle R&D programs.

[illegible]	[illegible]
Fiat's Panda Elettra	uses lead acid batteries that can be replaced with nickel cadmium or sodium sulfur battery packs
BMW's E1	uses sodium-sulfur batteries
Ford Minivan	uses sodium sulfur batteries
Ford's EcoStar	uses sodium sulfur batteries
U.S. DOE ETX-II	uses sodium sulfur batteries

Table 8-26. Sodium Sulfur Batteries in Electric Vehicle R&D Programs

8.11.3 NASA

Phillips Laboratory has sodium sulfur programs for the GEO Battery Flight Test Program and a Hot Launch Evaluation program.

Tables 8-27 and 8-28 list North American and foreign players in the sodium sulfur batteries R&D effort.

INDUSTRY	LABORATORIES	UNIVERSITIES
ABB Advanced Battery Systems - Canada	Argonne National Laboratory	Illinois Institute of Technology
Beta Power Inc.	Idaho National Engineering Laboratory	Stanford University
Ceramatec	Lawrence Berkeley Laboratory	University of Tennessee
Electrotek Concepts Inc.	National Renewable Energy Laboratory	University of Utah
Hughes Aircraft	Phillips Laboratory	University of Wisconsin
Powerplex Technologies	Sandia National Laboratory	Virginia Polytechnic
SAIC	Wright Patterson Air Force Aeronautical Laboratory	
SRI International		
Silent Power		
Thermacore Inc.		
U.S. Advanced Battery Consortium		

Table 8-27. North American Sodium Sulfur R&D Players

COUNTRY	INDUSTRY
England	Chloride Silent Power Limited
Germany	ASEA Brown Boveri AG
Japan	Hitachi
	Yuasa
	Nastech

Table 8-28. Foreign Industry Sodium Sulfur R&D Players

8.12 Technology Trends Summary

Figure 8-1 illustrates a summary of technology trends for battery chemistries.

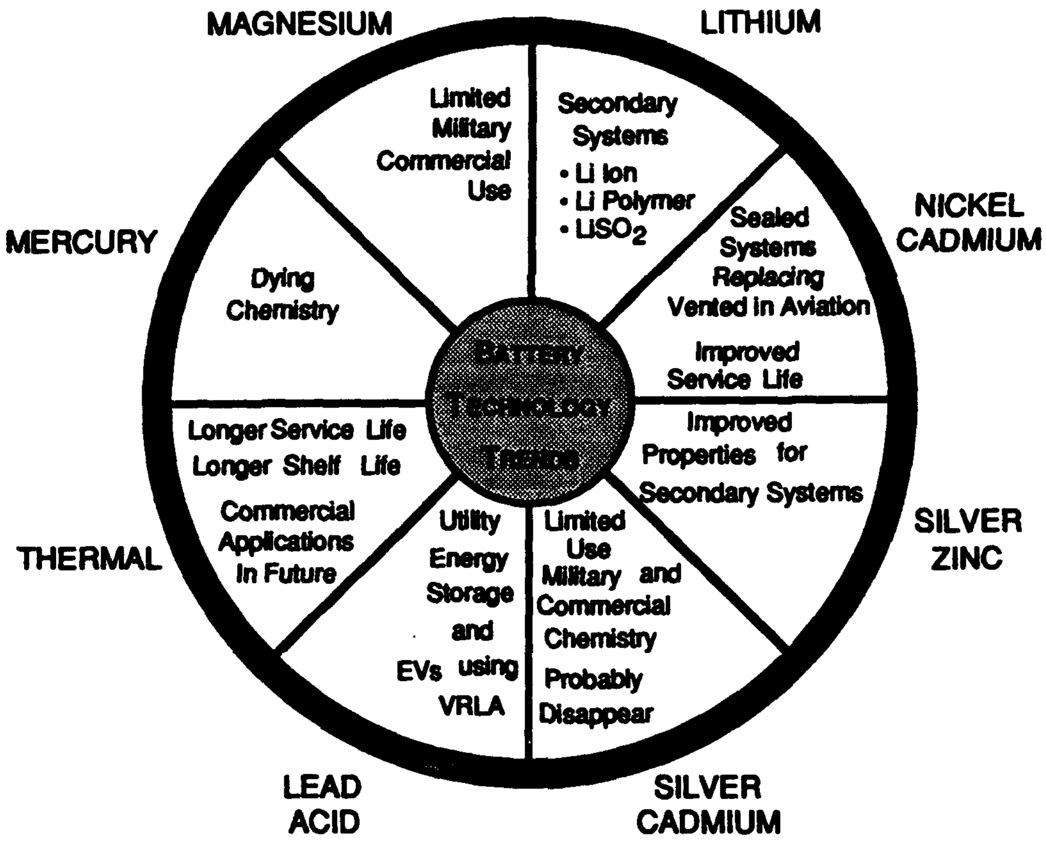

Figure 8-1. Battery Technology Trends Summary

8.13 Other Research

8.13.1 Army

Other Army research programs involve fuel cells and alternative power sources. For fuel cells the Army is interested in compact systems for manportable devices like the soldier system and silent diesel sources for systems such as the tank silent watch and for field power generation. Thermophotovoltaic power generation is an alternative power source that the army is researching.

In the next generation of radios, the Army would like electronics that can determine the charge left in the radio, thereby alleviating the need to remove the battery and check the charge with a tester. Two possibilities have been identified for a state-of-charge technology internal to the battery: a fuel gauge system (similar to the external meter TS-4403A) and a go/no go light system. Both require additional circuitry in the battery, need to be compatible with state-of-charge technology internal to the end item, and would need to be proven cost effective compared to external meter usage.

Another alternative the Army Research Laboratory (ARL) is considering a state-of-charge technology internal to the end item. ARL would like to see this technology implemented by the year 2000+ and feel this design will prove most cost effective and require zero effort from the user. Two systems are being examined: a fuel gauge and a clock. An internal meter may require additional circuitry in the battery. The SINCGARS system has the only fielded internal technology to date. It uses a clock to roughly measure battery use. PCI has a CRADA with ARL to develop a Universal Battery Monitor.

8.13.2 Air Force

There is a major emphasis within the Air Force to standardize the batteries they use.

8.13.3 Navy

The Naval Surface Warfare Center - Crane is developing a database of battery information to help system designers find information on appropriate batteries that will fulfill their requirements. This will help to evolve standard families of battery cells and to stem the proliferation of system unique batteries. They currently are developing some battery military standards through the Aviation Battery Group. The Navy also is sponsoring publication of primary and reserve battery handbooks and helping to instruct users on battery selection and sizing.

The Office of Naval Research (ONR) Electrochemical Sciences Program has a number of ongoing 6.1 basic research programs. One program is studying the dynamics and structure/property relationships of electron and atom transfer at submicron spatial and subsecond time resolution. The emphasis of this initiative is on ultramicroelectrode, ultramicroelectrode array, and proximal probe techniques to investigate electrochemical processes in small dimensions.

ONR also has a biocorrosion program to understand the composition, structure, chemical, and biochemical interactions at interphases that are subject to microbial induced corrosion. A key thrust of this program is development of techniques and probes to investigate complex biochemical interphases in conjunction with materials and biological sciences efforts.

The University of Minnesota has an ARPA-Sponsored University Research Initiative with ONR to study bicontinuous emulsions for electrode structure development.

8.13.4 NASA

R&D initiatives include exploring the use of impedance spectroscopy as a tool for predicting cell performance, life, and quality. NASA Lewis Research Center has undertaken this effort and evaluated nickel cadmium, nickel hydrogen, and lithium sulfur dioxide cells. The researchers have found that cells of the same chemistry exhibit characteristic impedance spectra that relate to the manufacturer.

The Lewis Research Center has undertaken the definition of improved tests that will more closely evaluate separator characteristics as related to the actual cell environment. This publication is scheduled for completion by the end of FY94.

8.13.5 ARPA

Another TRP is developing a high energy density capacitor for, among other applications, power supplies. Teaming on this effort are Power One Corporation, Polystore, Lawrence Livermore National Laboratories, Aerojet Corporation, and Rockwell. ARPA also has contracted with Photovoltaics regarding research on solar charging batteries.

8.13.6 DOE

DOE is conducting research on three propulsion systems for the electric vehicle. One of these systems is a modular electric vehicle propulsion system. This program was initiated to develop modular components with common designs that would be adaptable to a wide range of electric vehicles. Components include a battery and a battery controller.

DOE developed advanced models of lithium ion cells and provided a basis for scale-up and the design of thermal management systems. This data and methodology were then turned over to USABC contractors.

In the Advanced Battery Technology Research and Development area of the Chemical Sciences Program of the Office of Basic Energy Sciences (BES), work is centered on new battery components, concepts, and systems and characterization methodologies. The DOE is conducting fundamental studies of electrodes, composite electrode structures, electrolytes, and interfaces including overcharge-overdischarge problems, power capability, and system cyclability. Characterization methodologies the BES is studying are problems of electrode morphology, corrosion, separator electrolyte stability, and stable microelectrodes. Other initiatives include computational chemistry, modeling and simulation, property predictions, phenomenological studies of reactions and interactions at critical interfaces, film formation, phase change effects on electrodes, and characterization of crystalline and amorphous materials.

Much of the fundamental battery research the DOE BES has done is ex-situ due to the complicated nature of battery systems and their associated materials. Several new techniques are emerging that permit study under in-situ conditions. Future DOE work in this area will probably entail exploring novel battery separators and the transport properties of electrode and electrolyte materials and surface films and researching charging circuits associated with advanced battery systems.

8.14 ManTech Initiatives

This section describes ManTech programs that the military services have sponsored.

8.14.1 Army

The Army is developing a family of more reliable, low-cost, pellet-type thermal batteries capable of withstanding the high spin forces associated with artillery shells. Another Army ManTech program dealt with improved lead dioxide electroplating technology to improve battery lifetimes by correcting problems with the anodization of nickel prior to lead dioxide plating.

8.14.2 Air Force

The Air Force initiated a ManTech effort to develop a reliable, low-cost manufacturing technology for space-quality 50 ampere hour nickel metal hydride batteries for use in LEO satellites. Previous designs for GEO applications were not suitable for LEO-type satellites. The program resulted in a production cost reduction of 70 percent at very low production rates. Another Air Force ManTech effort focused on establishing reliable, low-cost manufacturing methods including quality assurance/quality control methods for thermal batteries. Eight areas of battery construction were identified where potential benefits could be derived from advanced manufacturing methods. The program resulted in a 20 percent cost reduction of thermal batteries. A second phase of the program developed improved processes to address each of the areas identified.

The Air Force has an ongoing ManTech project with LDEC and Eagle Picher Inc. (EPI) in Colorado Springs to control the variability of plates in cells, to determine critical processes, and to optimize production of sealed nickel cadmium batteries. The project, a two-year effort, began in September of 1993 with $1.7 million in funding. Eagle Picher also is presently qualifying a sealed nickel cadmium battery that may last 20 years for the B52 aircraft. If this battery proves successful, it will likely replace many sealed lead acid battery systems.

In another two year program, EPI is examining ways to improve EPI's manufacturing techniques and reduce and control variability in the manufacturing process.

8.14.3 Navy

The U.S. Navy has completed a ManTech program to improving the producibility of thermal batteries used in air strike weaponry. A critical requirement for fast reset times exceeded the design parameters of existing batteries.

9.0 BATTERY MARKETPLACE ANALYSIS

This section analyzes the battery marketplace by chemistry considering the military and commercial demand of each chemistry and the impact of this demand on the future supply of military batteries. It also assesses the health of each company within the battery chemistry markets by the following factors: the military and commercial demands for a specific chemistry from each supplier, the company's manufacturing capabilities and posture, the commercial market, and the production trends. It identifies requirements to establish a healthy industrial base for each chemistry. Finally, it discusses the projected business climate for commercial and military battery chemistries in the next five to ten years. This discussion addresses convertibility between the commercial and military industrial bases and highlights battery chemistries required by the military that do not and may never have a viable commercial base.

9.1 Thermal Battery Marketplace Analysis

The following analysis examines the military thermal battery marketplace; the commercial market for thermal batteries is practically non-existent.

9.1.1 Military/Commercial Demand

The demand for thermal batteries exists solely in the military sector. Work has been done without success to investigate and identify commercial/industrial applications. Military applications are limited as well. With the downsizing of weapon systems such as missiles, torpedoes, sonobuoys, and the long shelf life of thermal batteries, demand for these batteries has dramatically decreased. A recent military R&D development is attempting to implement thermal battery systems within a new line of sonobuoys. These products have used lithium sulfur dioxide batteries in the past; to date, only prototype systems have been demonstrated with the thermal battery system. This new application, however will, require only about 100,000 sonobuoys over a three year period. Another new military application that will slightly increase demand for thermal batteries is the BAT smart missile. However, this system will require less than 1,000 battery systems per month. Potential emergency power applications for commercial systems such as the More Electric Aircraft (e.g. - where electric actuators replace hydraulic landing gear systems) may initiate the commercial demand for thermal batteries. Present thermal battery demand is adequately met by the one supplier.

9.1.2 Health of Thermal Battery Suppliers

North America has only one producer of thermal batteries, Eagle-Picher Industries (EPI) in Joplin, Missouri. EPI is a large, multi-faceted company that does not rely heavily on military sales in its battery divisions; however, the Joplin facility is the only North American thermal battery manufacturing facility and is completely dependent on military customers. Even after a disastrous fire in 1991 which almost completely destroyed their thermal battery manufacturing facility and large fines for asbestos infractions, the company showed a profit in 1993. Figure 9-1 summarizes the general health of the entire company and its future expectations.

Thermal Battery Manufacturer	% of Sales to Government	Established Commercial Market	Non-Battery Products	Own Company or Division of Larger	Present		Future	
					Unhealthy	Healthy	Unhealthy	Healthy
Eagle-Picher (Joplin)	100	YES	YES	DIV		●		●

Figure 9-1. Health of Thermal Battery Manufacturers

New players are attempting to increase their presence in the thermal battery market. Martin Marietta is leasing a Department of Energy facility in Pinellas, Florida to increase its manufacturing capability within their R&D efforts, and Westinghouse Naval Systems Group has demonstrated limited prototype thermal battery manufacturing capability at their facility in Cleveland, Ohio. Recently, SAFT in Cockeysville, Maryland also has expressed interest in reentering the thermal battery marketplace in limited fashion if demand required additional suppliers.

9.1.3 Establishment of Healthy Commercial Base

Potential commercial applications in the More Electric Aircraft could begin the establishment of a commercial market for thermal batteries. If applications are identified, existing or prospective thermal battery producers will meet the demand easily.

9.1.4 Projected Business Climate for Thermal Battery Industry

Without commercial demand or increased military applications, the marketplace likely can support only one producer. The thermal market is stable presently and postured to remain stable and flat in the near future. There is a potential for thermal batteries to be used as backup power for the More Electric Aircraft and possibly automobiles. As aircraft move away from hydraulic systems and into electric actuators, the need for emergency power increases dramatically. The long shelf life, high power, and short life span of thermal batteries are a perfect fit for these applications. When and if this commercial application matures it will greatly add demand to the thermal market.

9.1.5 Convertibility of Industrial Base

With no present commercial demand for thermal batteries, the military demand defines the production base. If commercial applications arise for thermal batteries, the batteries probably will begin production within a military manufacturing facility.

9.2 Lithium Battery Marketplace Analysis

The following analysis considers the military lithium battery marketplace and the commercial lithium marketplace as it affects the military marketplace.

9.2.1 Military/Commercial Demand

Lithium batteries are used primarily in military applications with some spin-off into commercial applications. The military's need for high power and environmentally extreme operation has been met by lithium batteries, mainly lithium sulfur dioxide. Lithium sulfur dioxide batteries, though not as safe as household alkalines, are a reliable power source. The high cost of lithium sulfur dioxide batteries and surplus inventory from the Gulf War have prompted the military, mainly CECOM, to complete existing contracts for these batteries. Existing contracts and high inventory levels should satisfy lithium battery needs through 1998. At that time, when additional procurements of batteries are neede' 'ECOM hopes that a more cost effective lithium based system will be available. This battery s, _ will continue to be the lithium sulfur dioxide battery if its lifecycle costs are reduced, or it will be a replacement chemistry such as lithium manganese dioxide if its performance can be improved and lifecycle cost can be kept low. The

Navy also uses lithium sulfur dioxide batteries and is looking to lithium thionyl chloride as a possible replacement in the near future.

The present market for lithium batteries is only a fraction of the total portable battery market. Most of the battery demand for consumer portable electronics is filled today by nickel cadmium batteries and probably soon by nickel metal hydride. Advances in electronics and increases in portable electronic devices will create a demand by consumers for batteries that provide longer service life. This demand presents an opportunity for rechargeable lithium systems. These rechargeable systems, lithium ion and lithium polymer, will not be introduced until the life cycle, discharge rate, reliability, safety, and competitive cost have been demonstrated. The lithium ion system is more likely to achieve these goals than the lithium polymer system. The lithium ion battery already has reached the commercial market via Sony in support of Sony camcorders.

Commercial demand for lithium batteries will grow steadily through the year 2000. This growth will continue as secondary lithium batteries, such as lithium ion, proliferate the market. Existing applications for photographic equipment and memory backup constitute most of the commercial market. Small, niche applications such as mine lighting and medical equipment add to commercial demand.

9.2.2 Health of Lithium Battery Suppliers

The following analysis assesses the health of the military lithium battery suppliers in North America. Health is assessed by considering military and commercial sales, existing contracts, present depth in commercial market, business split between military and commercial markets, and variety of products. Yardney Technical Products is not presently a military supplier of lithium batteries, but the general company health is described because of the other related products and battery chemistries that it manufactures. Figure 9-2 summarizes the general health of each company's present situation and its future expectations.

Lithium Battery Manufacturers	% of Sales to Government	Established Commercial Market	Non-Battery Products	Own Company or Division of Larger	Present		Future	
					Unhealthy	Healthy	Unhealthy	Healthy
Ballard Battery Sytems	100	NO	NO	DIV	●		●	
Battery Engineering Inc.	20	YES	NO	DIV		●		●
Power Conversion Inc.	70	SMALL	NO	DIV		●		●
SAFT America	64	SMALL	NO	DIV		●	●	
Yardney Technical Products	0	SMALL	NO	OWN		●		●

Figure 9-2. Health of Lithium Battery Manufacturers

9.2.2.1 Ballard Battery Systems Corporation

Ballard manufactures lithium sulfur dioxide batteries for the U.S. and Canadian military. During the Gulf War they accelerated production and met increased demand as required. They presently have a contract with CECOM to supply lithium sulfur dioxide batteries through 1994. When this contract ends, Ballard will have no demand for its product. Ballard is working on development of lithium manganese dioxide batteries, which it (and CECOM) hopes will be a cost effective replacement for lithium sulfur dioxide batteries. Ballard also is working with the U.S. Air Force on development of a rechargeable lithium sulfur dioxide battery for use as emergency backup power in missile silos. Ballard is working on lithium ion rechargeable technology, but both lithium manganese dioxide and lithium ion batteries have yet to reach any level of regular production.

Ballard's present situation is unhealthy. They are in a niche market with limited product diversity. Their posture is to remain a small niche manufacturer and supplier of limited battery types. Their forecast is that the lithium manganese dioxide battery will create a $25 to $30 million a year business and they plan to enter this market. If Ballard does not succeed in entering this market, the future of the company will be in jeopardy.

9.2.2.2 Battery Engineering Inc.

Battery Engineering Inc. (BEI) manufactures primary lithium thionyl chloride batteries mostly for the oil drilling industry. BEI's military sales are confined to OEMs and some sales to GSA. BEI has no direct sales to the DoD or DND. They have a well established commercial/industrial market satisfying a niche requirement in the oil drilling industry and other niche markets such as batteries for animal tracking devices. Their lack of knowledge concerning entrance into governmen [illegible] nd their Japanese ownership have led BEI to believe that they are not considered a viable supplier for the DoD.

With a recently expanded facility, an established niche market, and very little dependence on DoD/DND customers, BEI feels they are strong and have steady to growing business for the next five years. The only catastrophe to BEI would be a sudden discovery of huge oil assets. As oil becomes a dwindling resource, increased drilling and exploration to find additional oil deposits will continue, as will the demand for BEI's batteries. BEI is in good to excellent health.

9.2.2.3 Power Conversion Inc.

Power Conversion Inc. (PCI) manufactures primary lithium sulfur dioxide, lithium manganese dioxide, and lithium thionyl chloride batteries with 70% of their sales to the military, mostly lithium sulfur dioxide batteries. PCI's present contract with CECOM will end late in 1996. PCI does not foresee any continued production of lithium sulfur dioxide batteries at that time. PCI's lithium thionyl chloride battery sales are mainly in the commercial arena for such things as aftermarket sales for portable computers and clocks. Presently they are pursuing the use of lithium thionyl chloride batteries in electronic residential gas, water, and electric utility meters. The advantage of these meters is that the meter attendant can drive by the residence and read the utility meter electronically without stopping the vehicle. PCI also is working on development of a lithium manganese dioxide "pouch" battery that could serve as the replacement for the military's lithium sulfur dioxide battery. Motorola also is very interested in this battery for portable radios and pocket pagers. 3M has expressed interest in the pouch battery to power medical electronics worn on the human body.

PCI foresees a $40 million per year market in foreign countries for lithium manganese dioxide batteries in support of U.S. supplied PRC radios. PCI feels they will run out of military business before they can reach full scale production of these systems. Their new posture is to

move into markets where the government is not the driver or main customer; they feel they need a legitimate commercial presence to remain successful, but this will take time. Due to decreased military demand PCI has already downsized once by closing their Puerto Rico manufacturing facility in January of 1993. PCI's health is uncertain.

9.2.2.4 SAFT America (Valdese, NC)

SAFT's main product in lithium battery technology is lithium sulfur dioxide batteries with 90% of sales for domestic or foreign military applications. In 1993 SAFT lost an $80 million contract with the Army due to diminished requirements and Gulf War surplus of lithium sulfur dioxide batteries. At that time SAFT felt they would not survive into 1994, but they have since received a contract from CECOM to supply lithium sulfur dioxide batteries through the end of 1996. During the Gulf War, SAFT invested $3 million of their own money to ramp up production for the contract with the Army and presently has a large excess capacity.

SAFT's excess capacity, reliance on a sole source supplier of their battery separator component, and decreased military demand have placed SAFT in a perilous situation. Presently, with $18.6 million in total TRP funds through CECOM, SAFT is pursuing lithium ion technology. Unless they can develop new customers and/or new product supplies, SAFT-Valdese may become an unhealthy company.

9.2.2.5 Yardney Technical Products

A major interest in Yardney was owned by Whittaker Corporation until 1990 when Yardney separated from Whittaker through a management buyout. Yardney manufactures primary and secondary silver zinc batteries and secondary silver cadmium batteries for the military and commercial market. Yardney also manufactures lithium thionyl chloride batteries for the commercial market. In 1993 Yardney's military battery sales accounted for 75% of their total sales. Of that 75%, silver zinc batteries comprised 90%, which were mostly secondary silver zinc systems. Commercial sales of silver zinc batteries accounted for 5% of Yardney's 1993 sales, and the remaining 20% of 1993 sales were lithium thionyl chloride batteries. Presently Yardney is operating at 50% capacity in their production facilities.

Yardney's main business is in silver zinc and silver cadmium batteries. Yardney has the capability to manufacture nickel hydrogen cells for space applications, but declining demand has prompted Yardney to cease production of this product. They built additional lithium sulfur dioxide

battery production capability to support the Gulf War requirements but the line was never used for military production. When the war started, other manufacturers received production orders, but Yardney was not qualified for production and thus never began production of military lithium sulfur dioxide batteries. Approximately 20% of their present business is for commercial lithium thionyl chloride batteries for oil drilling electronics and memory backup applications. The other 80% of their business is in the silver battery arena. Yardney feels their lithium business is stable but not growing; the demand should be steady as long as the portable electronics market remains active or until there are significant advances into new battery chemistries.

Yardney's lithium business is stable, but their silver battery business is on the decline, due mostly to decreased military sales. The company is hoping that in the 1996-1997 time frame their lithium ion battery development has matured enough to enter that new market.

9.2.3 Establishment of Healthy Commercial Base

Health of the lithium battery marketplace depends on commercial/industrial sales of rechargeable and primary batteries for products such as consumer portable electronics. The military demand in support of present and future systems will be limited. Manufacturers are attempting to diversify their product base and place greater emphasis on the commercial market. Many manufacturers today do not have separate production lines for military and commercial batteries and those that do will likely convert military battery lines to support dual production.

Although present commercial demand for lithium batteries is far less than military demand, this situation will change in the next few years as the military completes existing contracts for lithium sulfur dioxide batteries. The maturation of new lithium primary and rechargeable batteries will increase commercial applications and demand.

The future of the lithium based companies is to transition into the commercial marketplace yet continue to support the needs of the military. Manufacturers cannot afford to dedicate part of their facility solely to production of military batteries. For this to succeed the military cannot continue to use specialty batteries produced in small batch sizes. Some companies already have begun diversification into the commercial market, but other companies' existence is based on sales only to the military. The steady growth of the portable consumer electronics market and the demand for higher power, longer lasting (primary and secondary) batteries will provide the military with similar batteries from the commercial base. The aftermarket sector for replacement lithium batteries likely will be dominated by the large volume manufacturers such as Duracell, Eveready,

and Rayovac. The companies that supply the military with lithium batteries do not have the capital or desire to become a volume manufacturer like these commercial companies, but they do desire a strong commercial presence that will support their needs.

9.2.4 Projected Business Climate for Lithium Battery Industry

Product diversification based on increased commercial demand is paramount for a healthy lithium battery industry. The product diversification will take the suppliers away from military mainstay lithium sulfur dioxide batteries and into other, more commercially desirable lithium chemistries such as primary lithium manganese dioxide and secondary lithium ion. The survival of the lithium battery industry may occur through commercial sales of primary and newly developed secondary lithium batteries in support of portable consumer electronics. The military may lose some lithium suppliers in the near term, but not enough to eliminate competition; decreasing dollars and demand dictate the need for fewer suppliers. Some manufacturers believe that the military will continue to buy lithium sulfur dioxide batteries after expiration of existing contracts. No other lithium system offers the favorable properties of power, service life, and shelf storage life like lithium sulfur dioxide. Replacement electrochemical systems are available, or will be in the near future, to satisfy reduced requirements of the lithium sulfur dioxide system, but the question is what performance trade-offs are acceptable in conjunction with battery cost.

The lithium domestic market is projected to increase for both primary and secondary batteries through 2000. This growth will come from the commercial market with increased demand and sales of portable electronic devices. Military demand may no longer dictate the climate of the lithium marketplace.

9.2.5 Convertibility of Industrial Base

Most lithium battery manufacturers do not have dedicated lines to produce military batteries, and some even manufacture their commercial batteries in accordance with mil-specs. Some companies have excess production capacity due to increases during the Gulf War, but hope that commercial demand will compensate for the decrease in military demand. In certain instances the transition from primary to secondary lithium battery manufacturing (e.g. - lithium sulfur dioxide to lithium ion) will constitute large capital investments for new equipment. Most companies are postured in peacetime to treat their commercial and military customers equally. The companies will add additional shifts to meet extra military demand but will not make capital

investments to support military production alone. In a crisis situation, however, they will be well positioned to use their full capacity to support military production.

There are some TRPs assisting military based lithium battery producers to make the transition to commercial products. This will provide financial stability and at the same time will maintain military battery production capabilities.

9.3 Mercury Battery Marketplace Analysis

The following analysis considers the military mercury battery marketplace and the commercial mercury marketplace as it affects the military marketplace.

9.3.1 Military/Commercial Demand

The demand for mercury batteries is small in both the military and commercial marketplace. Military mercury batteries are used to support legacy systems that date from the 1960's and early 1970's. Commercial mercury batteries are used for medical monitoring equipment. State laws and environmental concerns over mercury have severely affected sales and have encouraged a switch from mercury to other chemistries. CECOM, the major buyer of mercury batteries for the military, purchased very few in 1993, but mercury battery sales to all four Services of the U.S. military and to foreign governments in the first quarter of 1994 alone almost equaled all 1993 sales. The military uses many of these batteries in their legacy Magnavox radios, but CECOM is working to phase out these mercury batteries. Thirteen states already have banned the sale of commercial mercury batteries. Minnesota and New Jersey have offered exemptions for medical equipment batteries, but the trend is eventually to ban mercury batteries throughout the U.S.

9.3.2 Health of Mercury Battery Suppliers

Alexander Batteries is the only North American supplier of mercury batteries; the only other supplier is Gold Peak in Hong Kong. Figure 9-3 summarizes the general health of Alexander Batteries' present situation and its future expectations.

Mercury Battery Manufacturer	% of Sales to Government	Established Commercial Market	Non-Battery Products	Own Company or Division of Larger	Present		Future	
					Unhealthy	Healthy	Unhealthy	Healthy
Alexander Batteries	80	YES	YES	OWN		•	•	

Figure 9-3. Health of Mercury Battery Manufacturers

In 1993 Alexander had only $423,000 in mercury sales to the military, a decrease of approximately $800,000 from the previous year. This continues a significant downward trend from $3.7 million in 1990 military sales. Alexander has considered leaving the mercury battery business and offered to sell its mercury capability to Gold Peak, but at the same time, Gold Peak offered to sell its capability to Alexander. Alexander has asked the government to help them remain viable to support legacy systems. One avenue that Alexander could follow is to become a government owned and contractor operated (GOCO) facility; no decisions have been made yet.

9.3.3 Establishment of Healthy Commercial Base

The commercial base for mercury batteries consists of one manufacturer with declining commercial business. In years past military demand has also been declining. The first quarter mercury demand for 1994 has been uncharacteristically high. After inventories are replenished and legacy systems disappear demand will undoubtedly decrease rapidly. With environmental concerns and more benign chemistries as an alternative to mercury batteries, this market will disappear soon.

9.3.4 Projected Business Climate for Mercury Battery Industry

The next five to ten years probably will see the demise of the domestic mercury battery industry. As legacy military systems are replaced and other battery chemistries make their way into the commercial market, the demand for mercury batteries will be almost nonexistent.

9.3.5 Convertibility of Industrial Base

Since mercury batteries will be used in increasingly fewer military applications and will eventually phase out, the adaptation of these batteries between the commercial and military markets is not necessary. Current demand for these batteries is clearly defined, and the customers will replace the mercury chemistry with new chemistries as they emerge.

9.4 Silver Battery Marketplace Analysis

The following analysis considers the military silver cadmium and silver zinc battery marketplace and the commercial silver cadmium and silver zinc marketplace as it affects the military marketplace.

9.4.1 Military/Commercial Demand

The commercial marketplace uses silver zinc batteries for niche applications. Small primary cells are used to power hearing aids and wristwatches; secondary batteries are used to power portable electronics, television news cameras, and video recorders. The military uses silver zinc batteries for torpedoes, unmanned undersea vehicles, swimmer delivery vehicle propulsion, and missile telemetry, control, and rocket stage separation. Silver cadmium batteries are used commercially in limited numbers for power tools and by the military for torpedoes. Both of these chemistries (except for the small hearing aid, wristwatch applications) have found more use in the military than the commercial sector. The high cost of these batteries is a limiting factor to increase the commercial market. Secondary silver zinc and silver cadmium batteries offer high energy and power density and excellent voltage regulation and charge retention but offer decreased service life compared to a nickel cadmium battery.

The military probably will use silver zinc batteries in missiles and torpedoes for some time, but declining defense dollars and decreased global threat will reduce quantities. Commercially, the electronic news gathering business will remain at least stable or grow. The same holds for the small cell commercial market. Silver cadmium batteries do not have a large military or commercial market. Other batteries from research and development should replace these silver chemistry systems in the future; the lithium family of batteries could likely replace some of the silver systems.

9.4.2 Health of Silver Battery Suppliers

Commercial primary silver zinc cells used for hearing aids and wristwatches are manufactured by Duracell, Eveready, and Rayovac. For military applications, the U.S. has four identified manufacturers of silver zinc batteries: BST Systems Inc., Eagle-Picher Industries Inc. (Joplin, Missouri facility), Whittaker Power Storage Systems, and Yardney Technical Products. Yardney and BST also manufacture silver cadmium batteries. Figure 9-4 summarizes the general health of each company's present situation and its future expectations.

Silver Battery Manufacturers	% of Sales to Government	Established Commercial Market	Non-Battery Products	Own Company or Division of Larger	Present		Future	
					Unhealthy	Healthy	Unhealthy	Healthy
BST Systems	80	SMALL	NO	OWN		•		•
Eagle-Picher (Joplin)		YES	YES	DIV		•		•
Whittaker Power Systems	100	NO	NO	DIV		•	•	
Yardney Technical Products	75	SMALL	NO	OWN		•		•

Figure 9-4. Health of Silver Battery Manufacturers

9.4.2.1 BST Systems

BST currently has a healthy military customer base and small, niche commercial customer base. They are positioned well to meet increased production requirements as evidenced during the Gulf War when the company added manufacturing personnel to meet the higher demand; normally, the facility operates under maximum capacity. BST is aware that the silver battery demand from military customers is decreasing due to defense cutbacks, but they intend to adapt to whatever production requirements arise in the future. In addition, BST continually attempts to update battery performance and capability in their private R&D programs, and they hope these programs will allow them to maintain a powerful battery line for both military and commercial

customers. Presently, the company's production operations are stable, but their future depends on military demands and improved technology.

9.4.2.2 Eagle-Picher Industries (EPI), Joplin, Missouri

EPI's primary reserve silver zinc batteries are used in many missile systems, and they will likely become the sole source supplier of these batteries in the future due to defense cutbacks and downscaling. They are the primary supplier of these batteries. EPI's other battery production, including other silver chemistries, thermal, and nickel cadmium, has placed them in a healthy production situation for both present and future demand.

9.4.2.3 Whittaker Power Storage Systems

Whittaker's customer base is exclusively military and government programs. This presents unstable conditions for Whittaker's future business since military scale down reduces demand for their batteries. Whittaker plans to maintain sales as high as possible and rely on R&D efforts to dictate future courses of action. Currently Whittaker has no plans to change the production capacity of their Denver, Colorado facility but does expect capacity utilization to drop as customer demand drops. Whittaker's business will decrease and stabilize at lower production levels.

9.4.2.4 Yardney Technical Products Inc.

See first paragraph section 9.2.2.5 for additional information.

Yardney at present is stable and pursuing improved silver zinc battery characteristics for the Navy, researching lithium ion batteries for NASA, and maintaining their commercial lithium business. Yardney hopes to transition additional parts of their business into the commercial sector but is mainly a military battery supplier. Yardney expects military sales to decrease in the next year or two and cannot be sure of future production requirements from military customers. A large downturn in military business could severely hurt Yardney, and they are experiencing cutbacks in their silver battery demands. Yardney's situation today is best described as stable, and they will remain stable as long as they maintain their present customer base.

9.4.3 Establishment of Healthy Commercial Base

For silver zinc batteries the commercial base is distinct from the military, due mainly to the battery type used in each market. High volume manufacturing of small cells for hearing aids and wristwatches does not compare with small runs of torpedo propulsion batteries. Silver batteries cannot be manufactured on the same line for both commercial and military applications as is the case with some of the lithium, lead acid, or nickel cadmium batteries.

For silver cadmium batteries the commercial base and demand are small. Environmental concerns over cadmium and near term potential replacement chemistries probably will cause the demise of the silver cadmium electrochemical system.

9.4.4 Projected Business Climate for Silver Battery Industry

The future of the silver battery industry will be dictated primarily by military and aerospace applications. Silver zinc primary battery annual sales in the U.S. are expected to grow from $15 million in 1992 to approximately $18 to $20 million in 2000. Secondary silver zinc battery annual sales in the U.S. are expected to grow from $32 million in 1992 to approximately $60 to $80 million in 2000. Silver zinc battery usage within the military will grow in the near future with improved silver zinc batteries. Research is ongoing to improve the properties and life cycle of silver zinc batteries. NASA should continue to use many silver zinc batteries. Eagle-Picher claims that every manned space flight from Mercury through Gemini, Apollo, and now the Space Shuttle have used their silver zinc batteries. Cost is the primary drawback for increased silver zinc battery demand, but this cost is compensated by its performance and reliability characteristics.

9.4.5 Convertibility of Industrial Base

The commercial base (small primary cells for small applications) is very different from the military base. Some overlap exists for certain applications like electronic news gathering equipment, but for the most part the military will never package a silver zinc battery using multiple button cells. Thus little potential for convertibility between commercial and industrial production exists.

9.5 Lead Acid Battery Marketplace Analysis

The following analysis considers the military lead acid battery marketplace and the commercial lead acid marketplace as it affects the military marketplace.

9.5.1 Military/Commercial Demand

The lead acid market is dominated by commercial demand. The only military application of lead acid batteries that has no commercial counterpart is submarine propulsion, due primarily to the large size of the battery system. The largest commercial demand for lead acid batteries is in the automotive aftermarket and for standby and motive power applications. Past, present, and future commercial demand has created a very stable and growing marketplace. Lead acid companies that supply the military have strong commercial markets, and the loss of military sales will not damage the market presence of these companies.

Commercial demand for lead acid batteries remains strong because the battery is relatively inexpensive, very safe and reliable, and although heavy due to the lead content, utilized in applications where weight is not a paramount issue. The development of valve regulated lead acid (VRLA) batteries between 1975 and 1980 has virtually eliminated the loss of water on charge and created a much safer battery. The electrolyte is completely immobilized, nearly eliminating the possibility of spilling or spraying if the battery is damaged. An extensive environmental program exists for the recycling of lead acid batteries; approximately 95% of all lead acid batteries produced in the U.S. are recycled. This recycling includes not only the lead but also the plastic container and battery acid.

9.5.2 Health of Lead Acid Battery Suppliers

Most lead acid battery manufacturers have a strong commercial/industrial market for their products. Most manufacturers have defined a section of the lead acid market that they supply and have chosen to stay in that area. For example, Concorde manufactures lead acid batteries primarily for aviation, while C&D Charter produces lead acid batteries primarily for standby power and automotive applications. Figure 9-5 summarizes the general health of each company's present situation and its future expectations.

Lead Acid Battery Manufacturers	% of Sales to Government	Established Commercial Market	Non-Battery Products	Own Company or Division of Larger	Present: Unhealthy	Present: Healthy	Future: Unhealthy	Future: Healthy
C & D Charter	1.3	YES	YES	DIV		•		•
Concorde Battery	20	YES	NO	OWN		•		•
GNB Battery Technologies	1.25	YES	YES	DIV		•		•
Johnson Controls	0	YES	YES	DIV		•		•

Figure 9-5. Health of Lead Acid Battery Manufacturers

9.5.2.1 C&D Charter Power Systems

C&D's government business accounted for 1.3% of their total 1993 sales. C&D manufactures lead acid batteries for the military in support of the Trident submarine and the Minuteman missile silo standby/backup power. C&D is the sole supplier of these Minuteman silo batteries. The company is not looking to expand its government sales, although the demand for Minuteman lead acid batteries recently has increased twelve fold and C&D will continue to satisfy this demand (originally the contract was supposed to end in June 1994).

If C&D lost their military business it would have little to no effect on the company. The company is healthy due to its strong commercial market and almost insignificant government sales.

9.5.2.2 Concorde Battery Corporation

Concorde has an established commercial base, supplying 40% of all commercial general aviation aircraft batteries in the U.S. They also produce older model lead acid batteries for the automotive aftermarket. Approximately 20% of Concorde's 1993 total sales were to the government, of which 75% were sealed lead acid battery sales. Concorde is a small company and is attempting to gain a foothold in the military aircraft battery market. Concorde's lead acid

batteries have been used on U.S. military cargo aircraft and on some of Canada's F18 fighter aircraft as a retrofit from nickel cadmium batteries. The military batteries that Concorde produces are manufactured on the same line as the commercial batteries.

Concorde's business is steady and stable and they hope to see more of their batteries used on military aircraft. With an established commercial market and military market and the potential for military sales growth, Concorde's situation is healthy.

9.5.2.3 GNB Battery Technologies

GNB has 20 manufacturing facilities in North America and claims to be the largest battery manufacturer in North America. GNB has a well established commercial business with approximately 1.25% of their total 1993 sales to the U.S. government. These lead acid batteries were used primarily on submarines, Navy ships, and in missile silos. GNB expects the military market to decrease in the next five years and is concentrating efforts on other battery technologies for commercialization.

GNB is a very healthy company which supplies the U.S. military with niche batteries. GNB claims that submarine batteries are *not difficult* to manufacture, just larger than most other batteries. The company relies very little on military sales.

9.5.2.4 Johnson Controls Battery Group

The Johnson Controls Battery Group (JC-BG) produces one out of every three automotive batteries sold in the U.S. under various brand names. This automotive aftermarket accounted for 85% of JC-BG's battery sales in 1993, up 4.5% from the previous year. The JC-BG has no identified sales to the U.S. government but has had sales to the Canadian Defense Department for backup power systems.

The JC-BG's well established commercial base and non-reliance on military sales indicated they are very healthy.

9.5.3 Establishment of Healthy Commercial Base

The commercial base for lead acid batteries is well established and growing. The applications for standby and motive power coupled with the automotive applications will keep this

base strong and healthy. The electric vehicle may serve as another avenue of growth for the lead acid battery industry, but research programs will determine success in this market.

9.5.4 Projected Business Climate for Lead Acid Battery Industry

With an established commercial market, the lead acid battery industry is expected to continue strong growth into the year 2000. U.S. sales of lead acid motive power batteries are expected to increase from $310 million in 1992 to $400 million in 2000; standby power batteries from $280 million in 1992 to $415 million in 2000; consumer lead acid batteries from $160 million in 1992 to $300 million in 2000; and automotive lead acid battery sales from $2350 million in 1992 to $3000 million in 2000.

9.5.5 Convertibility of Industrial Base

The commercial base is much larger than the military base and the products are basically the same. Except for configuration differences, military and commercial lead acid batteries are manufactured on the same production lines.

9.6 Nickel Battery Marketplace Analysis

The following analysis considers the military nickel battery marketplace and the commercial nickel marketplace as it affects the military marketplace.

9.6.1 Military/Commercial Demand

The military's largest use of nickel cadmium batteries is aviation. These batteries supply backup power and starting power to fighter and transport aircraft as well as helicopters. These same batteries are used commercially for general aviation and commercial aircraft (e.g. - Boeing and McDonnell Douglas). Most of the aviation nickel cadmium battery producers have a larger commercial than military market. The portable consumer electronics batteries on the shelves of stores are not used in military applications.

As defense dollars and programs decrease and the life of nickel cadmium batteries improve, there will be decreased demand for these batteries. The sealed nickel cadmium batteries are stored easily (in a discharged state), have a long shelf life, and a long service life. The Air Force is working to retrofit vented nickel cadmium batteries with sealed and ultra-low maintenance vented

nickel cadmium batteries in the F16 and E8 AWACS aircraft. The future demand for nickel cadmium batteries could be jeopardized by growing concerns over the toxic cadmium used in the batteries. This concern is part of the Air Force's rationale for switching to sealed nickel cadmium batteries. The Air Force will use fewer sealed nickel cadmium batteries, and, therefore, fewer batteries will need disposal. The military demand for these batteries will decrease as these retrofits occur, but commercial demand will remain stable.

Nickel metal hydride batteries are receiving a lot of attention as a potential replacement for nickel cadmium batteries. Nickel metal hydride batteries have not yet reached maturity but claim to offer increased performance and decreased manufacturing cost compared to nickel cadmium batteries. The absence of cadmium also is a significant environmental advantage.

9.6.2 Health of Nickel Battery Suppliers

The following company analysis assesses the health of the military nickel battery suppliers in North America. Health is assessed by considering military and commercial sales, existing contracts, present depth in commercial market, business split between military and commercial markets, and variety of products. Figure 9-6 summarizes the general health of each company's present situation and its future expectations.

Nickel Cadmium Battery Manufacturers	% of Sales to Government	Established Commercial Market	Non-Battery Products	Own Company or Division of Larger	Present		Future	
					Unhealthy	Healthy	Unhealthy	Healthy
Eagle-Picher Industries	5	YES	NO	DIV		●		●
Marathon Power Technologies	17	YES	NO	OWN		●		●
SAFT America	50	YES	NO	DIV		●		●

Figure 9-6. Health of Nickel Battery Manufacturers

9.6.2.1 Eagle-Picher Industries Inc. (EPI) (Colorado Springs, CO)

EPI is a very large and diverse company that has weathered a fire at one facility and asbestos claims against the company. The company showed profits in 1992 for the first time in many years. The EPI Colorado Springs facility manufactures nickel cadmium and nickel hydrogen batteries for aviation and aerospace. The nickel hydrogen batteries are actually part battery and part fuel cell and are used for aerospace applications such as satellites. Approximately 5% of EPI's nickel cadmium sales are to the military in support of military aircraft. EPI presently is working with the U.S. Air Force to retrofit their sealed nickel cadmium batteries on B52 aircraft to replace either SAFT or Marathon vented nickel cadmium batteries. Commercial and military nickel cadmium batteries are manufactured on the same production lines.

EPI believes the aircraft industry is not healthy, and they are concerned about military aviation cutbacks. They have been working with the Air Force to develop a 20 year nickel cadmium battery. EPI is hoping that the Air Force will continue with plans to retrofit aircraft with sealed nickel cadmium batteries. Presently EPI's operations in Colorado Springs are stable and healthy.

9.6.2.2 *Marathon Power Technologies*

Marathon manufactures nickel cadmium batteries primarily for aviation. Approximately 17% of Marathon's sales are to the U.S. government (military, Immigration and Customs, and the Treasury Department). Marathon claims they supply 90% of Canada's aviation batteries and that Marathon nickel cadmium batteries have been on F16 aircraft from the beginning of that program. Although government sales have dropped off in recent years, total demand is still stable. Marathon manufactures government and commercial batteries on the same production lines.

Marathon believes they could survive without the government business and that the nickel cadmium battery industry is strong. They believe customers will choose higher power nickel cadmium batteries over lead acid batteries for certain applications. Marathon's established commercial market, non-reliance on government business, and their impending sale indicate a stable and healthy company.

9.6.2.3 SAFT America (Valdosta, GA)

SAFT is part of a large, worldwide French-owned company. The Valdosta facility manufactures nickel cadmium batteries for aviation and industrial applications. SAFT's sales to the military account for 32% of their total sales but account for 50% of their total production volume. SAFT is working with the Army and Air Force to encourage use of SAFT's ultra low maintenance nickel cadmium batteries for aviation.

SAFT expects the commercial and military nickel cadmium markets to converge but noted they would not return if they ever left the military business. SAFT claims they make little profit on military sales, but they fill the factory with work and help cover overhead costs. In 1993 SAFT realized a decrease in OEM and aftermarket (replacement) battery sales and an increase in military sales. SAFT production facilities are presently running at 50% of capacity and therefore could handle increased customer orders. SAFT is hoping that their new ultra low maintenance nickel cadmium batteries find a market niche as a replacement for conventional vented nickel cadmium batteries. If SAFT lost their military business it is not likely that they would close their doors. Presently SAFT's situation is healthy.

9.6.3 Establishment of Healthy Commercial Base

The commercial base for aviation nickel cadmium batteries is well established. Most manufacturers have a larger commercial than military aviation battery demand, although commercial demand is decreasing. Military nickel cadmium aviation batteries, for the most part, use the same production lines as commercial aircraft batteries.

9.6.4 Projected Business Climate for Nickel Battery Industry

McDonnell Douglas is already using sealed nickel cadmium batteries on its MD-80 and DC-9 commercial aircraft; the military is using them on a few F-16 fighters and Apache helicopters; and Boeing is expected to use them on the 777 aircraft. Most other commercial and general aviation aircraft use vented nickel cadmium batteries. The advantages of using sealed nickel cadmium batteries include lower maintenance costs, longer life, and easier logistics. Nickel cadmium batteries require less service, making them easier to deploy worldwide in support of military aircraft. The sealed nickel cadmium battery is more consistent with the goal of having the battery serviced in conjunction with the service of the aircraft. The Air Force is expected to begin retrofitting aircraft with sealed and ultra-low maintenance vented nickel cadmium batteries during

1994. Commercial demand for sealed nickel cadmium batteries is projected to increase from $440 million in 1992 to $520 million by the year 2000.

Nickel metal hydride batteries are just entering the commercial market. Primary use of these batteries has been in support of personal notebook computers. Nickel metal hydride batteries are projected to reach a $100 million market by the year 2000.

9.6.5 Convertibility of Industrial Base

For aviation nickel cadmium battery suppliers, the commercial industrial base and military industrial base are basically the same. Most manufacturers produce military and commercial batteries on the same production lines, and for a sudden increase in military demand, additional shifts could be implemented to meet all production requirements.

9.7 Magnesium Battery Marketplace Analysis

The following analysis considers the military magnesium battery marketplace and the commercial magnesium marketplace as it affects the military marketplace.

9.7.1 Military/Commercial Demand

The use of magnesium batteries by the military is limited to a few applications. The Navy uses them for mines, and the Army uses them as a lower cost alternative to lithium batteries during training exercises for portable electronics equipment.

9.7.2 Health of Magnesium Battery Suppliers

There are two domestic suppliers of magnesium batteries to the military. ACR Electronics manufactures magnesium batteries in support of the Navy's Captor mines and Rayovac sells batteries to CECOM that the Army uses in portable electronics during training exercises. Figure 9-7 summarizes the general health of each company's present situation and its future expectations.

Magnesium Battery Manufacturers	% of Sales to Government	Established Commercial Market	Non-Battery Products	Own Company or Division of Larger	Present: Unhealthy	Present: Healthy	Future: Unhealthy	Future: Healthy
ACR Electronics	20	YES	YES	DIV		•		•
Rayovac		YES	YES	OWN		•		•

Figure 9-7: Health of Magnesium Battery Manufacturers

9.7.2.1 ACR Electronics

ACR's sales of magnesium batteries to the military account for 20% of their total sales. ACR is the single source supplier of the Navy Captor (MK 125, 126, 127) batteries and has sold 550,000 of these to the Navy over the last ten years. ACR's commercial magnesium market is small, mostly in support of the emergency locator electronics that they manufacture. They do not see much growth in this market and would discontinue this capability altogether if they were to cease manufacturing magnesium batteries for the military. ACR's present and future situation is stable and healthy.

9.7.2.2 Rayovac

Rayovac makes batteries primarily for the consumer and industrial electronics markets. The magnesium batteries are sold to the military off the commercial line and are used to support equipment during training exercises. Rayovac historically has had a number of firsts in the battery industry and is the 326th largest privately owned company in the U.S. Its main competition is Eveready and Duracell. Rayovac is the third largest battery manufacturer in the U.S.

Rayovac's large commercial base along with their standing as a consumer battery market supplier indicates a healthy company. Rayovac's military sales are negligible compared to their commercial sales; a loss of military contracts would have little or no effect on the company.

9.7.3 Establishment of Healthy Commercial Base

Presently the commercial market for the magnesium batteries is stable, and except for a few dual-use batteries used by both commercial and military customers, the markets are distinct. The commercial market dominates the demand for magnesium batteries.

9.7.4 Projected Business Climate for Magnesium Battery Industry

The commercial demand will continue to dominate. Military applications are few and not expected to grow significantly. The manufacturers of magnesium batteries will remain focused on their commercial customers unless a new battery is developed through research and development programs. Most new products, both military and commercial, probably will use other battery chemistries.

9.7.5 Convertibility of Industrial Base

There is no further need to adapt commercial magnesium batteries for military needs. The batteries which the military uses are commonly used in the commercial market already and few additional demands on battery specifications are expected in the future.

9.8 Summary

"Dual use" will not exist in the near future in the sense that the military will be able to power equipment with batteries they could buy off the shelf of a retail store. Dual use will exist in the sense that the battery manufacturers will have established commercial production lines/facilities that will support production of batteries that are sold to both commercial and military customers. This concept of dual use in production terms will be the measure of whether a chemistry will continue to be manufactured into the 21st century. Production lines will manufacture the same cells and configure/repackage the cells in accordance with the specific battery system requirements.

Figure 9-8 summarizes the status of the North American military battery industry by chemistry. Figures 9-9 and 9-10 identify potential battery replacements for particular primary and secondary battery chemistries. Replacement of one chemistry with another depends on application and mission requirements. For example, lithium sulfur dioxide batteries can be replaced with magnesium manganese dioxide batteries but at a reduced performance level in certain environments. For primary systems, lithium manganese dioxide, magnesium manganese dioxide,

and lithium sulfur dioxide batteries have several possible replacement systems. For secondary battery systems, nickel cadmium, secondary silver zinc, and silver cadmium are common today but probably will be replaced by one of several options.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Thermal	medium military demand no commercial demand potential for emergency power systems in commercial	one healthy supplier others considering entry	healthy	stable and flat	N/A
Lithium	military demand for lithium sulfur dioxide decreasing increased military interest in other lithium chemistries small commercial demand commercial demand for lithium ion and lithium polymer increasing	five companies with poor to good health concern for 1995 to 1997 time frame	diversification from military to commercial market is a concern due to rapid military decrease and slow commercial increase military transition to lithium manganese dioxide should support at least two suppliers suppliers looking for commercial market to sustain business	need product diversification based on increased commercial demand	lithium sulfur dioxide likely to be replaced by lithium manganese dioixde lithium thionyl chloride dual use today (bobbin config) lithium ion dual use for future
Mercury	military demand decreasing small, niche commercial demand	presently stable eventually supplier will disappear	not required	market going away	N/A
Silver	mostly military demand some commercial demand	four suppliers with fair to good health	healthy silver cadmium going away	stable but overall demand decreasing may lose one supplier	N/A
Lead Acid	high commercial demand piggy-back military applications new commercial applications for future	four healthy suppliers	healthy	exellent and expanding	full convertability and dual use
Nickel Cadmium	high commercial demand piggy-back military applications	three healthy suppliers	healthy	excellent and expanding	full convertability and dual use
Magnesium	small military demand small commercial demand	two healthy suppliers	healthy	stable and flat	Army uses dual use batteries Navy does not use dual use batteries

Figure 9-8. Status of North American Battery Industry by Chemistry

PRIMARY BATTERY CHEMISTRY	POTENTIAL REPLACEMENT
Lithium Manganese Dioxide	Lithium Carbon Monofluoride
	Lithium Sulfur Dioxide
Lithium Sulfur Dioxide	Lithium Manganese Dioxide
	Lithium Thionyl Chloride
	Magnesium Manganese Dioxide
Magnesium Manganese Dioxide	Lithium Sulfur Dioxide
	Lithium Thionyl Chloride
Mercury	Lithium Thionyl Chloride
Primary Silver Zinc	Lithium Thionyl Chloride
(Reserve) Thermal	Reserve Lithium Thionyl Chloride
	Reserve Silver Zinc

Figure 9-9: Potential Primary Battery Replacement Systems

SECONDARY BATTERY CHEMISTRY	POTENTIAL REPLACEMENT
Lead Acid	Nickel Cadmium
Nickel Cadmium	Lead Acid
	Lithium Ion
	Nickel Metal Hydride
Secondary Silver Zinc	Lithium Ion
	Nickel Cadmium
	Nickel Metal Hydride
	Nickel Zinc
Silver Cadmium	(Advanced) Silver Zinc
	Nickel Metal Hydride

Figure 9-10: Potential Secondary Battery Replacement Systems

10.0 CONCLUSIONS AND RECOMMENDATIONS

The following section presents conclusions and recommendations of this battery industrial base study. The first section discusses conclusions and recommendations by chemistry, and the second section discusses conclusions and recommendations to improve management of the battery marketplace.

10.1 Conclusions and Recommendations by Chemistry

In general, manpower and monetary cutbacks have forced the military to do more with less. The battlefield of tomorrow will be controlled by electronics; from small manportable devices to large weapon systems, all will be mobile and require some form of electrical power to operate. Doing more with less necessitates the use of a flexible base rather than an independent, specialized base to satisfy particular needs. Drawing from a commercial and industrial base can satisfy this "more with less" requirement. Competition in a growing marketplace keeps prices low and availability high. This creates inherent stability. For certain sections of the battery marketplace, such as lead acid and nickel cadmium batteries, stability is present because of the largely established commercial and industrial markets. For chemistries such as lithium sulfur dioxide, silver zinc, or silver cadmium, the market has been centered in the past (and somewhat in the present) around the military. For these systems reliance on the military as the main customer has been a cause of instability.

The North American military battery industrial base can be described in three groups. The first group comprises military unique batteries that have no commercial counterpart customer or application. These military unique batteries and configurations, namely thermal systems and primary reserve silver zinc, are at risk since military defense cutbacks are placing suppliers in unhealthy production situations. Suppliers are unlikely to dedicate portions of their facilities to unique batteries that do not require high or consistent production rates.

The second group comprises batteries that have commercial counterparts or significant military demand that is not affected by defense cutbacks. Availability of these batteries is not in jeopardy. The battery chemistries and configurations in this group are lithium, primary and secondary silver zinc (not primary reserve), lead acid , and nickel cadmium.

The final group comprises batteries that currently have both military and commercial demand but whose military demand likely will phase out during the next decade. Although the

manufacture of these batteries for military applications will decrease it is likely that many systems that use these batteries will still have them in service for a period of time after the military terminates its procurement of the batteries. These batteries are used in older technologies, have environmentally unfriendly components, or are expensive. Battery chemistries in this group include magnesium, mercury, and silver cadmium. Military customers are positioning their applications to implement other battery chemistries or configurations.

The following sections present the conclusions based on the status of the chemistries discussed throughout this report and recommendations that the U.S. and Canadian governments should consider for each chemistry.

10.1.1 Thermal Batteries

10.1.1.1 Conclusions

Eagle-Picher in Joplin, Missouri is the only North American producer of thermal batteries. The only current customer market for thermal batteries is the military. The industrial base decline to a single producer was due primarily to reduced demand. The one supplier is stable; there is a potential that others, Martin Marietta and Westinghouse, may enter the market for future military and commercial applications.

10.1.1.2 Recommendations

The U.S. and Canadian governments do not need to perform any action in this family of batteries. The current applications and the anticipated additional military and commercial applications are expected to maintain a stable market and dictate the total number of thermal battery suppliers. However, the U.S. and Canadian governments must be cognizant of the impact that further demand decreases could have on the supplier base.

10.1.2 Lithium Batteries

10.1.2.1 Conclusions

The lithium marketplace traditionally has been maintained by one customer - the military via sales of mostly primary lithium sulfur dioxide batteries. Although the military uses other lithium batteries such as lithium thionyl chloride and lithium manganese dioxide, the lithium sulfur dioxide

electrochemical system has been the most popular because of its high energy and long service and shelf life. The Gulf War, combined with existing contracts, eliminated the need for additional, large procurements of lithium batteries until the 1997 or 1998 time frame. CECOM, the largest customer for lithium sulfur dioxide batteries, believes there will be a more cost effective chemistry available when their battery demands rise, either lithium sulfur dioxide systems with reduced lifecycle costs or an improved, inexpensive replacement system such as the lithium manganese dioxide pouch cell.

Of the four major military lithium battery manufacturers, Ballard, Battery Engineering Inc. (BEI), Power Conversion Inc., and SAFT, only BEI relies more on its commercial demand than its government demand. The other three rely heavily on government customers. A fifth company, Yardney Technical Products, which manufactures silver based batteries for the military, manufactures lithium batteries for the commercial market. They also have the capability to manufacture military lithium sulfur dioxide batteries and are a potential military lithium battery supplier, but today, this manufacturing line sits idle.

The lack of commercial demand and heavy reliance on the military as a customer creates uncertainty for the companies' (or divisions') future. Efforts are ongoing at SAFT, PCI, and Ballard to transition into the commercial market. The impediment is that they first need a commercial battery, commercial demand for that battery, and the capability to mass produce that product. All three of the companies are optimistic about achieving this goal eventually, but the interim transition is a concern. Optimally, as military sales decline, commercial sales will increase to maintain a satisfactory level of sales.

The planned retreat from what was previously the military's (and the manufacturers') mainstay chemistry, lithium sulfur dioxide, has left the lithium military industrial base floundering on how to survive through the next five to ten years. They plan to fulfill the remaining contracts to the military and simultaneously work toward diversifying their product and customer base.

10.1.2.2 Recommendations

During the next few years, the military should focus their efforts on decreasing lithium sulfur dioxide lifecycle costs and improving lithium manganese dioxide and lithium thionyl chloride performance and safety. Also, the military should be aware of the supplier diversification that will be dictated by current and anticipated military and commercial demands. The anticipated demands will have a direct effect on the suppliers' diversification efforts.

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R&D efforts on lithium ion and lithium polymer secondary battery systems should continue in order to improve performance and maintain low lifecycle costs. These two battery systems are important to the lithium family since they may replace the current lithium systems if their performance specifications are satisfactory and their lifecycle costs remain low.

10.1.3 Mercury Batteries

10.1.3.1 Conclusions

The mercury electrochemical system at one time was a mainstay product for the military in communications equipment, but new, improved chemistries and increased knowledge and awareness of mercury's toxicity have made it an undesirable chemistry. The military still utilizes mercury batteries in legacy communications systems, naval mines, and surveillance systems. The medical field also uses commercial mercury batteries. The environmental concerns regarding mercury have prompted 13 states to ban the sale of mercury batteries; others will likely follow.

Worldwide only two mercury battery manufacturers exist: Alexander in the U.S. and Gold Peak in China. Alexander Batteries relies heavily on the U.S. military for sales of its mercury batteries. In previous years Alexander's mercury operation has lost money, but during the first quarter of 1994, the mercury business outperformed the total 1993 sales. This is an aberration; as the military replaces legacy systems with new systems that use lithium based batteries, the demand for mercury batteries will decrease dramatically. These diminished demands coupled with environmental concerns will most likely lead to the demise of the mercury electrochemical system.

10.1.3.2 Recommendations

The transition from mercury batteries should continue. The military and government agencies are aware of this and need only to ensure current systems using mercury batteries continue to transition to other chemistries and/or replace legacy systems with other systems that use other chemistries.

10.1.4 Silver Batteries

10.1.4.1 Conclusions

Silver zinc batteries satisfy niche applications in the military and commercial markets. They are used commercially in electronic news gathering equipment and specialized medical equipment. Silver zinc batteries' main military applications are guidance and telemetry for missiles and propulsion of underwater systems.

Silver cadmium batteries satisfy an even smaller market than silver zinc. They are used in missiles, torpedoes, limited aerospace applications, and portable power tools. The silver cadmium battery may, at some time, be replaced with a less expensive, more environmentally friendly battery chemistry. Advanced silver zinc and nickel metal hydride batteries are likely candidates.

The silver battery marketplace is driven by the military with four identified suppliers - BST Systems, Eagle-Picher Industries, Whittaker Power Storage Systems, and Yardney Technical Products. The marketplace is healthy with a projected stable business climate. Sufficient military demand exists to sustain at least three manufacturers in the future.

10.1.4.2 Recommendations

Although the military silver battery demand has been decreasing, the production base is stable enough to warrant little action. However, the military should remain cognizant of the suppliers' status since some specific silver configurations are in higher demand than others. For example, the primary reserve silver zinc production will likely decrease to a single supplier due to decreased demand for this specific configuration. This, in affect, becomes similar to the thermal battery scenario, a sole supplier for limited demand with production potential at other supplier facilities.

10.1.5 Lead Acid Batteries

10.1.5.1 Conclusions

Lead acid batteries are the most widely used rechargeable battery system in the world, and the manufacturing process and the battery product are proven, economical, and reliable. Lead acid batteries have a solid position in the commercial marketplace for applications running the gamut

from aviation to automobiles to portable electronics. Inexpensive materials and almost complete recycling of used batteries have made lead acid batteries affordable and very available. Military use of lead acid batteries is varied. Submarine propulsion, vehicular starting, lighting, and ignition, aviation, and standby power are the main military applications, but military purchases of lead acid batteries are small in comparison to sales in the commercial/industrial market. The lead acid battery industry, especially for aviation, automotive, and standby power applications, is strong and growing steadily.

10.1.5.2 Recommendations

Since the lead acid battery marketplace is very strong and healthy, no actions are required.

10.1.6 Nickel Cadmium Batteries

10.1.6.1 Conclusions

Nickel cadmium batteries are also a mature technology and show no signs of decline. The nickel cadmium marketplace is supported heavily by commercial aviation and industrial/commercial sales. All the identified military nickel cadmium battery suppliers have a strong established commercial and military market. Military and commercial batteries are manufactured on the same production lines.

10.1.6.2 Recommendations

As with the lead acid family, since the nickel cadmium battery marketplace is stable and healthy, no actions are required. However, the military should continue its R&D efforts concerning the nickel metal hydride battery since it has demonstrated potential to replace several existing battery chemistries in the future.

10.1.7 Magnesium Batteries

10.1.7.1 Conclusions

The military use of magnesium batteries is limited to mines and communications equipment. The battery system is an old chemistry that will likely be phased out over the next few decades.

There is only a single North American manufacturer for the Navy mine batteries - ACR Electronics. Their manufacturing process is antiquated and labor intensive, but ACR has no plans to update their manu   ing equipment, processes or operations. ACR has a well established commercial market   on-battery products and although they would miss revenues from magnesium military batteries, if demand became low enough to make the economics unfavorable, ACR contends they would cease production. The Navy has not expressed a great deal of concern about this; other battery chemistries are potential replacements.

CECOM procures commercial, off the shelf batteries from Rayovac for its communications equipment as a low cost alternative to lithium sulfur dioxide batteries during training exercises. Rayovac is a well established battery company with a large commercial base; the military's purchases produce little income compared to their commercial market base.

Military and commercial demand in the magnesium battery market is small. The two identified suppliers are healthy with a stable business climate. Both suppliers are adequately diversified via other products so that the loss of military magnesium battery business would have no catastrophic effects on their companies.

10.1.7.2 Recommendations

Since the magnesium battery manufacturers are stable, no actions are required. The current applications for the battery should remain supported. If the military demand decreases or is terminated, the suppliers will not experience any significant problems.

10.2 Short Term Management Issues' Conclusions and Recommendations

This section presents conclusions and recommendations associated with management concerns raised by the battery industrial sector. Many of these concerns have been identified previously in section 7.1.

10.2.1 Joint U.S./Canadian Battery Buys and Joint Buys Between Services

10.2.1.1 Conclusions

Batteries are pervasive throughout the military. The Services use large quantities of batteries to maintain supplies and conduct training exercises. Canada procures a smaller portion of batteries than the U.S., and most Canadian military equipment comes from U.S. suppliers. Therefore, the Canadian DND uses many of the same batteries as the U.S., but currently there are no joint efforts in battery purchasing. There are very few Canadian battery suppliers; when Canada buys batteries from U.S. manufacturers, they often obtain them through a Canadian distributor at a premium. Joint purchasing programs directly from the manufacturer will help both the U.S. and Canadian governments as well as the battery manufacturer. The benefits for the two governments include decreased unit costs due to larger quantities and elimination of distributor premiums.

10.2.1.2 Recommendations

The U.S. Services and Canadian DND should explore the possibility of joint procurements among the Services and the DND.

10.2.2 Plan for Low Rate Production

10.2.2.1 Conclusions

In preserving a production base capability, both the production lines and the skill level of the people involved in the process need to be maintained. Extending production deliveries by planning for a low rate of production would achieve this goal. This helps not only to preserve a particular capability and chemistry, but also to ease the transition from one battery chemistry, e.g., lithium sulfur dioxide, to the next generation chemistry. This also enables the producer to make more informed business and investment decisions.

10.2.2.2 Recommendations

Though low rates of production increase costs they should be used where there is concern about maintaining a needed production capability that is in danger of disappearing. The lithium sulfur dioxide chemistry is a prime example; the Army is looking to transition to a more cost

efficient battery but needs to ensure that lithium sulfur dioxide chemistry production is available until the new chemistry is developed.

10.2.3 Improved Planning and Communication

10.2.3.1 Conclusions

Improved planning and communication of battery requirements with manufacturers would permit more efficient workloading and production scheduling. This would not only increase manufacturer stability and improve delivery schedules, unit costs, and quality, but also would serve to foster a better, more cooperative working relationship with battery producers.

10.2.3.2 Recommendations

The U.S. Services and Canadian DND should work toward improving the planning involved regarding battery supply requirements and relaying this information to manufacturers. Communication may be enhanced through the implementation of an electronic bulletin board informing manufacturers of future battery procurement requirements.

10.2.4 Battery Maintenance

10.2.4.1 Conclusions

Certain secondary batteries, such as nickel cadmium and lead acid used mainly for military aviation applications, have their service lives shortened by improper maintenance procedures. The lack of proper maintenance is a cause of significant annual cost in battery replacement.

10.2.4.2 Recommendations

The services should implement improved personnel training and update battery maintenance procedures. A thorough understanding of what maintenance is required and when it is required is imperative to preserve battery service life. This information should be obtained, when available, from the battery manufacturer and updated or incorporated into military battery maintenance procedures.

10.3 Long Term Management Issues' Conclusions and Recommendations

The following conclusions and recommendations suggest long term ways to eliminate and reduce other areas of concern.

10.3.1 Standardize Battery NSNs (NATO/National Stock Numbers)

10.3.1.1 Conclusions

The U.S. Services and Canadian DND need a better understanding of what batteries they have in use and where different organizations are procuring the same batteries from the same manufacturer but using different NSNs.

10.3.1.2 Recommendations

A thorough parsing of the battery NSNs of the U.S. and Canadian military services is required. The two countries should institute a process to coordinate and catalog new NSNs. A joint battery NSN database with explicit information about each item could facilitate this process. Currently, NSN lists exist that provide specific NSNs or categories of NSNs corresponding to a particular battery, but this information is often limited or inaccurate.

10.3.2 Make Better Use of a Battery Designers Associate (tool)

10.3.2.1 Conclusions

Though system designers attempt to identify and utilize existing batteries, they are frequently unsuccessful because they are unaware of existing batteries that could satisfy the needs of a particular system. A database that documents and tracks batteries could have a significant impact on reducing the proliferation of new batteries within the military. There are several existing databases that document and track either batteries or components of military systems, including batteries, which offer potential as such a system.

10.3.2.2 Recommendations

The U.S. Services and Canada should address whether one of the current databases could serve as a battery designers associate. The basis for this determination should be identifying what

information would need to be included or added to the selected database and what procedures would need to be developed to make it effective.

10.3.3 Create Families of Batteries

10.3.3.1 Conclusions

One way to help stem the proliferation of batteries is to ensure that battery requirements are considered in the early planning stages of a weapon system. If families of batteries were created for different defense systems, the designer could choose standard batteries from the family appropriate to his system and operational requirements. This standardization would help limit the number of configurations/chemistries used with specific systems. These families could highlight specific areas such as ordnance systems, communications systems, manportable devices, or aviation systems. The Navy has successfully accomplished this in designing sonobuoys. Duracell has standardized their commercial lithium camera battery configurations from which camera designers must choose a specific battery. A tri-Service Aviation Battery group is in place that could address this issue for aircraft batteries.

10.3.3.2 Recommendations

The U.S. and Canadian governments should jointly create families of batteries that contain sub-families for specific chemistries and configurations. These families should be organized by specific functional areas. These families will serve to standardize and control the proliferation of configurations/chemistries used with particular systems and will allow new batteries in the families to be designed with the same or similar parameters and specifications.

10.3.4 Evaluation of Supporting Mil-Specs

10.3.4.1 Conclusions

Some supporting military specifications that affect batteries are outdated and in need of revision. Packaging and shipping of batteries are a prime example. One battery producer indicated a requirement to ship their batteries in wooden crates. This was an expensive undertaking that added to the overall battery cost and did not allow the producer to take advantage of more cost effective materials.

10.3.4.2 Recommendations

Evaluation of supporting military specifications should be addressed jointly between the services and Canadian DND working in conjunction with battery manufacturers to determine which specifications are outdated, unnecessary, and/or too costly or stringent.

10.3.5 Make Better Use of Multiple- (or Multi-) Year Contracting

10.3.5.1 Conclusions

Additional multiple-year contracting would enable both the government and industry to plan their business strategies better. These contracts, which could be awarded for longer periods than in the past, (e.g. five to seven years), could be based on the past performance of the company. This would help establish a more cooperative, working relationship with companies.

10.3.5.2 Recommendations

Where possible, the U.S. Services and Canadian DND should support and utilize multiple-year contracting.

10.3.6 Oversight Function for the U.S. Services/DoD/Canadian DND

10.3.6.1 Conclusions

The U.S. Services and Canadian DND could be more effective in sharing battery information and working together to overcome common problems. Though small ad hoc groups exist to study specific battery issues dealing with particular areas, these efforts could be combined into a major battery oversight function between the U.S. Services, DoD, and Canadian DND.

10.3.6.2 Recommendations

A joint function between the U.S. and Canadian Services should be established to oversee management issues concerning batteries and the dissemination of information concerning battery research, buys, company status, and the status of the implementation of the above recommendations. Also, since the above recommendations cover a variety of issues and a variety

of areas, this joint function should oversee the planning, implementation, and progress of the efforts made to improve the battery industrial base.

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6	A SOLID SULFUR CATHODE FOR AQUEOUS BATTERIES	DHARMASENA PERAMUNAGE, STUART LICHT	8/20/93	SCIENCE
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18	ADVANCED BATTERY TECHNOLOGY RESEARCH AND DEVELOPMENT PROGRAM	STEVEN G. BARNHART	6/28 - 6/30/94	US DEPARTMENT OF ENERGY
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43	BATTERY ELECTROCHEMISTRY SECTION OVERVIEW	RICHARD A. MARSH	6/1/94	
44	BATTERY ENGINEERING & TESTING SERVICES	MR. JAMES GUCINSKI		NAVAL SURFACE WARFARE CENTER
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46	BATTERY GOALS FOR EV HYBRIDS	JOHN J. ROWLETTE AND DAVID L. HARBAUGH		ARIAS RESEARCH ASSOCIATES, INC.
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51	BATTERY SECTOR STUDY TRIP #4	DONALD HIGGINS	2/25/94	BDM FEDERAL
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60	CHALLENGES	TOM JACKSON	10/1/93	INTEL CORPORATION
61	CHARGE/DISCHARGE CHARACTERISTICS OF A FULL-SIZE SODIUM-SULFUR BATTERY FOR AN ELECTRIC VEHICLE	A. F. BURKE		IDAHO NATIONAL ENGINEERING LABORATORY

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66	COMSAT BATTERY TECHNOLOGY LICENSED TO EAGLE-PICHER			
67	CRITICAL REVIEW OF POLYMER ELECTROLYTE BATTERY TECHNOLOGY	B. M. BARNETT AND D. FAUTEAUX		ARTHUR D. LITTLE, INC.
68	CUSTOM DESIGNED AND STANDARD HIGH-ENERGY DENSITY LITHIUM/THIONYL CHLORIDE BATTERIES	BATTERY ENGINEERING, INC.		BATTERY ENGINEERING, INC.
69	DEFENSE SYSTEMS SILVER-ZINC BATTERIES			EAGLE PICHER
70	DEVELOPMENT AND MANUFACTURE OF A LARGE, MULTI-CELL LITHIUM THIONYL CHLORIDE RESERVE BATTERY	NORMAN A. REMER/JERRY NOLTING		ALLIANT TECHSYSTEMS INC./DEPARTMENT OF THE NAVY
71	DEVELOPMENT OF A RECHARGEABLE LI/SO2 BATTERY	LYNN MARCOUX		BALLARD BATTERY SYSTEMS CORPORATION
72	DISPOSAL OF LITHIUM BATTERIES AND THE POTENTIAL FOR RECYCLING OF LITHIUM BATTERY COMPONENTS	JOEL P. GUPTILL	1/20 - 1/21/94	BDT, INC.
73	DND BATTERIES ACQUISITION			DND CANADA
74	DOD KEY TECHNOLOGIES PLAN		7/1/92	DEPARTMENT OF DEFENSE
75	DOUBLE LAYER CAPACITORS SCALE UP FROM SMALL TO MEDIUM SIZE CELLS	DR. ANTHONY P. TRIPPE		MAXWELL LABORATORIES, INC.
76	ELECTROCHEMICAL POWER SOURCE PROGRAM	DR. GASTON VERVILLE		DND, CANADA
77	ELECTRIC AND HYBRID VEHICLES PROGRAM		5/1/93	US DEPARTMENT OF ENERGY
78	ELECTRIC AND HYBRID VEHICLES PROGRAM		8/1/93	US DEPARTMENT OF ENERGY
79	ELECTRIC AND HYBRID VEHICLES PROGRAM		1/7/94	US DEPARTMENT OF ENERGY
80	ELECTRIC AND HYBRID VEHICLES PROGRAM - 16TH ANNUAL REPORT TO CONGRESS FOR FISCAL YEAR 1992	U.S. DEPARTMENT OF ENERGY	5/1/93	U.S. DOE - OFFICE OF TRANSPORTATION TECHNOLOGIES
81	ELECTRIC VEHICLES: THEIR TECHNICAL AND ECONOMIC STATUS	TIMOTHYP. HENDERSON, MICHAEL RUSIN	1/1/94	AMERICAN PETROLEUM INSTITUTE
82	ELECTRIC VEHICLE BATTERY OPTIONS: PRESENT AND FUTURE	J. P. CORNU, J. EMBREY, J. LEONARDI, AND K. K. PRESS		SAFT

Appendix A - Material Database

ID #	Document Title	Author	Document Date	Source of Document
83	ELECTRIC VEHICLE DYNAMIC-STRESS-TEST CYCLING PERFORMANCE OF LITHIUM-ION CELLS	STEVEN T. MAYER		LAWRENCE LIVERMORE NATIONAL LABORATORY
84	ELECTRIC VEHICLES		11/1/92	IEEE SPECTRUM
85	ELECTRIC VEHICLES: TECHNOLOGY, PERFORMANCE AND POTENTIAL		1/1/93	INTERNATIONAL ENERGY AGENCY (IEA)
86	ELECTRIC/HYBRID ELECTRIC VEHICLE		10/1/93	ARPA
87	ELECTRICAL MEASUREMENTS	MCGRAW-HILL ENCYCLOPEDIA OF SCIENCE & TECHNOLOGY		VOLUME 10, 6TH EDITION
88	ELECTROCHEMICAL POWER SYSTEMS DEPARTMENT			NAVAL SURFACE WAREFARE CENTER/CRANE DIVISION
89	ELECTROCHEMICAL PROCESS	MCGRAW-HILL ENCYCLOPEDIA OF SCIENCE & TECHNOLOGY		VOLUME 10, 6TH EDITION
90	ELECTROCHEMISTRY BRANCH CODE R33	JAMES A BARNES		NAVAL SURFACE WARFARE CENTER
91	ELECTROEXPLOSIVE DEVICES	JAMES R. HARVEL		EAGLE PICHER
92	ELECTRONICS AND POWER SOURCES	SOL GILMAN	6/29/94	ARMY RESEARCH LABORATORY
93	EXPLORATORY TECHNOLOGY RESEARCH IN SUPPORT OF THE DOE ELECTRIC AND HYBRID POPULSION PROGRAM	A. R. LANDGREBE	4/1/94	DEPARTMENT OF ENERGY
94	EXPLORATORY TECHNOLOGY RESEARCH PROGRAM FOR ELECTROCHEMICAL ENERGY STORAGE	K. KINOSHITA	10/1/93	LAWRENCE BERKELEY LABORATORY, UNIVERSITY OF CALIFORNIA
95	FAST-CHARGE BATTERIES	ANNE WATSON SWAGER	12/7/89	POWER SOURCES
96	FEDERAL LABORATORIES RELATED TO FUEL CELLS	ROBERT W. BAIRD	8/10/93	NATIONAL TECHNOLOGY TRANSFER CENTER
97	FEDERAL LABORATORY DIRECTORY - TECHNOLOGY REINVESTMENT PROJECT ADVANCED BATTERY TECHNOLOGY			DELABARRE & ASSOCIATES, INC.
98	FIRE AT EAGLE PICHER/COUPLES PLANT JOPLIN, MISSOURI - BELLRINGER	ANDREW D. ROCHE	9/17/91	DLA
99	FIRE AT EAGLE PICHER/COUPLES PLANT JOPLIN, MISSOURI - FIRE ASSESSMENT AND STATUS REPORT	ANDREW D. ROCHE	10/14/91	DLA

ID #	Document Title	Author	Document Date	Source of Document
100	FIRE AT EAGLE PICHER/COUPLES PLANT JOPLIN, MISSOURI - SECTION I. EXECUTIVE SUMMARY	ANDREW D. ROCHE		DLA
101	FIRE AT EAGLE PICHER/COUPLES PLANT JOPLIN, MISSOURI - SECTION V, ANNEX E OSD TEAM INITIAL FINDINGS BRIEFING	ANDREW D. ROCHE	9/30/91	DLA
102	FIRE AT EAGLE PICHER/COUPLES PLANT JOPLIN, MISSOURI EAGLE-PICHER INDUSTRIES ELECTRONICS DIVISION	ANDREW D. ROCHE	11/14/91	DLA
103	FIRST INTERNATIONAL CONFERENCE ON POWER REQUIREMENTS FOR MOBILE COMPUTING AND WIRELESS COMMUNICATIONS		10/4 - 10/6/93	POWER '93
104	FRENCH FIRMS JOIN ON BATTERY VENTURE			FINANCIAL FOCUS
105	FRENCH THERMAL BATTERIES	INDUSTRY OUTLOOK	7/26/93	AVIATION WEEK & SPACE TECHNOLOGY
106	GY1994 FDT&E DESCRIPTIVE SUMMARY		12/1/93	FEDERAL SOURCES, INC.
107	HIGH ENERGY BATTERY NEWSLETTER	DEPARTMENT OF THE NAVY	10/1/93	NAVAL SURFACE WARFARE CENTER
108	HIGH-RATE LI-MN02 CELLS FOR AEROSPACE USE	R. BECKER-KAISER, J. RUCH, H.-J. HARMS, P. SCHMODE, J. R. WELSH, M.-J. VOLLMERS, H. PACK, M. LEMBO		HOPPECKE BATTERY SYSTEMS, INC.
109	HOW TO DETERMINE YOUR PRIORITY GROUP STATUS		1/4/92	THE CANADIAN CONTENT POLICY
110	HOW TO LIVE WITH A HYDROGEN BOMB AND EVERYTHING THAT YOU WANTED TO KNOW ABOUT A BATTERY BUT WERE AFRAID TO ASK?	ARNOLD J. HOROWITZ	3/8/93	
111	HYDRO-TECH		9/93 - 12 /93	HYDRO-QUEBEC
112	IAPG MEETING COMPENDIUM		1/1/93	HORIZON DATA CORPORATION
113	IAPG MEETING COMPENDIUM - INTERAGENCY ADVANCED POWER GROUP	POWER INFORMATION CENTER	1/1/93	POWER INFORMATION CENTER
114	IAPG MEMBERSHIP ROSTER - INTERAGENCY ADVANCED POWER GROUP	POWER INFORMATION CENTER	3/1/93	POWER INFORMATION CENTER
115	IASO REPORT ON EAGLE PICHER		8/17/93	EAGLE-PICHER INDUSTRIES, INC.
116	ICS GOING ON A 3-V DIET	BETTY PRINCE, ROELOF H. W. SALTERS	5/1/92	IEEE SPECTRUM
117	INMETCO	R. H. HANEWALD, M. E. SCHWEERS, J. C. ONUSKA		THE INTERNATIONAL METALS RECLAMATION COMPANY, INC.
118	ION RECHARGEABLE BATTERIES USING SYNTHESTIC ORGANIC POLYMERS	Y. ECHIGO, K. ASAMI, H. TAKAHASHI, AND K. INOUE, T. KABATA, O. KIMURA, AND T. OHSAWA		R&D CENTER
119	IS YOUR LITHIUM GETTING FURRY?	BARRY SHELL		SIMON FRASER UNIVERSITY

ID #	Document Title	Author	Document Date	Source of Document
120	JEC BATTERY NEWSLETTER NO. 6	ITE-JEC PRESS INC.	12/1/93	ITE-JEC PRESS INC.
?	JEC FAXBATTERY NEWSLETTER	ITE INC.	5/1/94	NO. 20
122	JOURNAL OF POWER SOURCES	LAWRENCE H. THALLER - GUEST EDITOR	3 & 4/88	NASA LEWIS RESEARCH CENTER
123	LEAD	WILLIAM D. WOODBURY	6/14/09	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
124	LEAD IN AUGUST 1993	BRANCH OF METALS AND BRANCH OF DATA COLLECTION AND COORDINATION	11/29/93	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
125	LEAD IN DECEMBER 1993	BRANCH OF METALS AND BRANCH OF DATA COLLECTION AND COORDINATION	3/2/94	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
126	LEAD IN JULY 1993	BRANCH OF METALS AND BRANCH OF DATA COLLECTION AND COORDINATION	11/18/93	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
127	LEAD IN JUNE 1993	BRANCH OF METALS AND BRANCH OF DATA COLLECTION AND COORDINATION	9/23/93	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
128	LEAD IN MARCH 1994	BRANCH OF METALS AND BRANCH OF DATA COLLECTION AND COORDINATION	5/26/94	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
129	LEAD IN OCTOBER 1993	BRANCH OF METALS AND BRANCH OF DATA COLLECTION AND COORDINATION	12/1/93	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
130	LEAD IN SEPTEMBER 1993	BRANCH OF METALS AND BRANCH OF DATA COLLECTION AND COORDINATION	12/8/93	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
131	LIGHTWEIGHT BATTERY CHARGERS FOR PRODUCTS ON THE GO	TERRY LEEDER		POWER INTEGRATIONS, INC.
132	LIGHTWEIGHT NICKEL ELECTRODES FOR NICKEL-HYDROGEN CELLS	HONG S. LIM AND GABRIEL R. ZELTER		INDUSTRIAL ELECTRONICS GROUP OF HUGHES AIRCRAFT COMPANY
133	LISTING OF MILITARY AND FEDERAL BATTERY SPECIFICATIONS FOR SHARP SBS TASK 1.5.1	SHIPBOARD BATTERY BRANCH	9/30/93	NAVAL SURFACE WARFARE CENTER
134	LITHIUM	JOYCE A. O BER	6/1/93	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
135	LITHIUM BATTERIES	SIGNALGRAM	5/1/91	OFFICAL PUBLICATION OF AFCEA
136	LITHIUM BATTERIES GROUP			EAGLE-PICHER INDUSTRIES
137	LITHIUM SULFUR-DIOXIDE BATTERIES	POWER CONVERSION, INC.		POWER CONVERSION, INC.
138	LITHIUM-MANGANESE OXIDE RECHARGEABLE BATTERY		1/4/93	CHEMICAL & ENGINEERING NEWS
139	LOWER BATTERY MAINTENANCE FOR HIGHER PERFORMANCE GAINS	SAFT AMERICA INC.		
140	MAKING METALS A REUSABLE RESOURCE	J. C. ONUSKA, M. E. SCHWEERS, P. A WHITVER	11/3/93	INMETCO

ID #	Document Title	Author	Document Date	Source of Document
141	MAKING METALS A REUSABLE RESOURCE		6/1/93	INMETCO
142	MANGANESE	THOMAS S. JONES	1/1/192	US DEPT OF THE INTERIOR
143	MANTECH PROJECT BOOK		1/1/92	MANUFACTURING TECHNOLOGY USAF
144	MANTECH PROJECT BOOK 1992		6/15/09	MANUFACTURING TECHNOLOGY USAF
145	MANUFACTURING METHODS FOR LITHIUM BATTERIES		8/31/79	WRIGHT-PATTERSON AFB
146	MANUFACTURING METHODS TO ESTABLISH RELIABLE MANUFACTURING PROCESSES FOR NICKEL-CADMIUM BATTERIES	EAGLE-PICHER INDUSTRIES, INC.	9/76 - 9/82	WRIGHT-PATTERSON AFB
147	MANUFACTURING PROCESS METHODS AND PROCEDURES FOR ZIRCONIUM POWDER PRODUCTION FOR THERMAL BATTERY APPLICATIONS	DONALD L. SMITH	10/31/79	WRIGHT-PATTERSON AFB
148	MANUFACTURING TECHNOLOGY FOR THERMAL BATTERY PRODUCTION	C. LYNCH	3/84 - 10/90	WRIGHT-PATTERSON AFB
149	MATERIALS SCIENCES CHARACTERIZATION OF A THERMAL BATTERY	DR. H. L. LEWIS AND MR. L. H. HAMMERSLEY		NAVAL WEAPONS SUPPORT CENTER CRANE
150	MDEA ANNEX ON RECHARGEABLE LITHIUM BATTERY R&D			DND, CANADA
151	MERCURY IN 1992	BRANCH OF METALS AND BRANCH OF DATA COLLECTION AND COORDINATION	7/27/94	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
152	MINERAL COMMODITY SUMMARIES 1993		1/1/93	BUREAU OF MINES
153	NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM	PATRICIA O'DONNELL	4/3/92	NASA LEWIS RESEARCH CENTER - POWER TECHNOLOGY DIVISION
154	NATIONAL TECHNOLOGY TRANSFER CENTER - OVERVIEWS OF SEVERAL FEDERAL LABORATORIES RELATED TO BATTERIES	ROBERT W. BAIRD	8/10/93	NATIONAL TECHNOLOGY TRANSFER CENTER
155	NAVAL FUEL CELL APPLICATIONS - THE DND APPROACH: UUVS	LDCR M. J. ADAMS	7/5/94	CANADIAN NAVY
156	NAVSEA BATTERY DOCUMENT	WESTINGHOUSE	7/1/93	CRANE NSWC
157	NAVAL SURFACE WARFARE CNETER CRANE DIVISION TRIP REPORT ON THERMAL BATTERY MANUFACTURERS LOCATED IN EUROPE	JOHN INMAN	1/13/94	JOHN INMAN
158	NAVY BATTERY DEVELOPMENT PROGRAMS: AN OVERVIEW	JAMES A. BARNES, CLINTON S. WINCHESTER	6/29/94	DEPARTMENT OF ENERGY
159	NAVY PRIMARY AND SECONDARY BATTERIES	DEPARTMENT OF THE NAVY	9/1/91	
160	NBC PROTECTIVE MASK BLOWER	A. J. SIPIN	7/6/93	SMALL BUSINESS ADMINISTRATION

ID #	Document Title	Author	Document Date	Source of Document
161	NEW HIGH ENERGY DENSITY BATTERIES		10/1/91	NEWS, RESEARCH, DEVELOPMENTS, CONTRACTS
162	NICD BATTERY CHARGER HIDES IN A AC-LINE PLUG	FRANK GOODENOUGH	8/19/93	ELECTRONIC DESIGN
163	NICKEL	PETER KUCK	4/1/93	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
164	NICKEL	PETER KUCK	12/1/93	US DEPARTMENT OF THE INTERIOR/BUREAU OF MINES
165	NICKEL CADMIUM BATTERY FLIES ONE YEAR WITH NO MAINTENANCE	AERSPACE DAILY	9/3/91	MCGRAW-HILL INC.
166	NICKEL METAL HYDRIDE, A FLIGHT EXPERIMENT	EDWARD A. FITZGERALD, DR. FRANCIS C. WESSLING		TELEDYNE-BROWN ENGINEERING/UNIVERSITY OF ALABAMA IN HUNTSVILLE
167	NICKEL- HYDRIDE CELLS AVERT ENVIRONMENTAL HEADACHES	CHARLES H. SMALL	12/10/92	POWER SOURCES
168	NICKEL-CADMIUM BATTERY FOR SUBMARINE APPLICATIONS	JACK T. BROWN, ELIO FERREIRA		ENERGY RESEARCH CORPORATION
169	NORTH AMERICAN DEFENSE INDUSTRIAL BASE ORGANIZATION (NADIBO) JOINT SECTOR STUDY WORKING GROUP	U.S. MARINE CORPS	8/17/93	US MARINE CORPS - MARINE CORPS LOGISTICS BASES
170	OEM CAPABILITIES DATA SHEET	PERIPHEX, INC.	7/7/93	PERIPHEX, INC.
171	OFFICE OF NAVAL RESEARCH ELECTROCHEMICAL SCIENCES PROGRAM	DR. ROBERT J. NOWAK	6/28 - 6/30/94	DEPARTMENT OF ENERGY
172	OPERATING AND MAINTENANCE MANUAL NICKEL-CADMIUM AIRCRAFT BATTERIES	SAFT AMERICA INC.		
173	ORDNANCE SYSTEMS OPERATION	TRISHA G. TUCKER		EAGLE PICHER
174	OVERVIEW OF BATTERY PROGRAMS AT JPL	GERALD HALPERT, RAO SURAMPUDI, SAL DI STEFANO	Jun-27-1994	JPL
175	OVONIC NICKEL METAL HYDRIDE RECHARGEABLE BATTERIES - TECHNOLOGY UPDATE	S. VENKATESAN, M. A. FETCENKO, P.R. GIFFORD, S. K. KHAR, S. R. OVSHINSKY		OVONIC BATTERY COMPANY
176	PERFORMANCE AND SAFETY CHARACTERISTICS OF PRIMARY LITHIUM MANGANESE DIOXIDE SYSTEMS	M. C. HART, E. P. THURSTON, W. ANDRUK, T. B. REDDY		POWER CONVERSION, INC.
177	PLANAR-PROFILE BATTERIES	RALPH J. BRODD, MAY P. ROSSOLL		GOULD INC.
178	POWER CELL TECHNOLOGY IN CANADA 1990	INDUSTRY SCIENCE & TECHNOLOGY CANADA	1/1/90	MICHAEL SLACK
179	POWER PACK	GARY STIX	10/1/93	SCIENTIFIC AMERICAN
180	POWER SOURCES II	RESEARCH AND DEVELOPMENT IN NON-MECHANICAL ELECRICAL POWER SOURCES, EDITED BY L. J. PIERCE	9/1/66	PROCEEDINGS OF 15TH INTERNATIONALPOWER SOURCES

ID #	Document Title	Author	Document Date	Source of Document
181	POWERBOOKS: THE NEXT GENERATION	CARY LU	7/1/94	MACWORLD
182	PRAM PROGRAM OFFICE FINAL REPORT - HIGH RELIABILITY MAINTENANCE FREE BATTERY (MRMFB) AIRCRAFT TEST	CRAIG-ALAN BIAS, CHRIS EDWARDS, HOWARD ADKINS	10/1/90	AIR FORCE SYSTEMS COMMAND
183	PRESENT STATUS OF LITHIUM-ION BATTERY TECHNOLOGY	V. R. KOCH	5/12/94	COVALENT ASSOCIATES, INC.
184	PRIMARY BATTERY	MCGRAW-HILL ENCYCLOPEDIA OF SCIENCE & TECHNOLOGY		VOLUME 10, 6TH EDITION
185	PROCEDDINGS OF THE 36TH POWER SOURCES CONFERENCE	VARIOUS	JUNE 6-9, 1994	POWER SOURCES CONFERENCE
186	PROCEEDINGS OF THE 35TH INTERNATIONAL POWER SOURCES SYMPOSIUM	INDUSTRY APPLICATIONS SOCIETY OF THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.	6/22 - 6/25/92	CLINTON WINCHESTER
187	PROCEEDINGS OF THE 6TH INTERNATIONAL MEETING ON LITHIUM BATTERIES	J. O. BESENHARD	5/1-5/15/92	MUNSTER GERMANY
188	PROCEEDINGS OF THE 7TH ANNUAL	BATTERY CONFERENCE ON APPLICATIONS AND ADVANCED	1/21-1/23/94	CALIFORNIA STATE UNIVERSITY, LONG BEACH
189	PRODUCT CATALOG	BATTERY SPECIALITIES		
190	PROGRAM FOR COLLABORATIVE RESEARCH INTO SMALL ARMS TECHNOLOGY (CRISAT)	NATO ARMY ARMAMENTS GROUP	9/30/93	NATO ARMY ARMAMENTS GROUP
191	PROGRAMS FOR COLLECTING, PACKAGING, TRANSPORTING AND RECLAIMING SPENT NICKEL-CADMIUM BATTERIES	J. C. ONUSKA, M. E. SCHWEERS, P. A. WHITVER	11/3/93	INMETCO
192	PROSPECTS FOR THE USE OF LITHIUM BATTERIES BY THE NAVY	CLINTON S. WINCHESTER, JAMES A. BARNES, PATRICK B. DAVIS, WENDY A. FREEMAN, SAYMOND A. SUTULA		NAVAL SURFACE WARFARE CENTER
193	PURE-LEAD BATTERIES ARE PURE GOLD	KALYAN JANA	5/15/93	TE&M SPECIAL REPORT: POWER AND PROTECTION
194	RECENT DEVELOPMENTS IN DOWTY, PRIMARY HIGH RATE LI/MNO2 BATTERIES	A.JEFFERY		DOWTY BATTERIES
195	RECHARGEABLE ALKALINE MANGANESE DIOXIDE BATTERIES	C. MONDOLONI, M. LABORDE, J. RIOUX, E. ANDONI, C. LEVY-CLEMENT	4/1/92	JOURNAL OF THE ELECTROCHEMICAL SOCIETY, VOL. 139 NO.4

ID #	Document Title	Author	Document Date	Source of Document
196	RECHARGEABLE ALKALINE MANGANESE DIOXIDE-ZINC CYLINDRICAL CELL TECHNOLOGY FOR CONSUMER APPLICATIONS	K. TOMANTSCHGER, J. BOOK, R. D. FINDLAY, S. GINTHER, P. GOODMAN		BATTERY TECHNLOGIES, INC.
197	RECHARGEABLE BATTERIES: AN UPDATE OF DEVELOPMENT AT WESTINGHOUSE	ENERGY	6/1/90	
198	RECHARGEABLE LITHIUM POLYMER ELECTROYTE BATTERIES	BOONE B. OWENS		CORROSION RESEARCH CENTER/UNIVERSITY OF MINNESOTA
199	RECHARGEABLE NICADS	YARDNEY		
200	RECHARGEABLE THIN-FILM LITHIUM MICROBATTERIES	J. B. BATES, G. R. GRUZALSKI, N. J. DUDNEY, C. F. LUCK, X. H. YU/S. D. JONES	7/1/93	OAK RIDGE NATIONAL LABORATORY/EVEREADY BATTERY CO.
201	RECYCLED METALS IN THE UNITED STATES	STAFF, DIVISION OF MINERAL COMMODITIES	10/1/93	US DEPT OF THE INTERIOR
202	RECYCLING LEAD AND ZINC THE CHALLENGE OF THE 1990'S	DAVE LARRABEE	6/11 - 6/13/91	US DEPARTMENT OF COMMERCE
203	RECYCLING NICKEL-CADMIUM BATTERIES	SUSAN COHEN	4/1/93	RESOURCE RECYCLING
204	REMARKS BY GASTON BASTIAENS AT THE BIS POWER '93 CONFERENCE		10/4/93	APPLE COMPUTER, INC.
205	REPORT OF ACTIVITIES		1/1/92	HYDRO-QUEBEC
206	RESERVE BATTERY	MCGRAW-HILL ENCYCLOPEDIA OF SCIENCE & TECHNOLOGY		VOLUME 10, 6TH EDITION
207	RISK REDUCTION MONOGRAPH NO. 1: LEAD	ENVIRONMENT DIRECTORATE	1/1/93	ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
208	RUBBERY CONDUCTORS AIM AT BETTER BATTERIES	I. PETERSON	3/13/93	SCIENCE NEWS, VOL. 143
209	RUBBERY SOLID ELECTROLYTES WITH DOMINANT CATIONIC TRANSPORT AND HIGH AMBIENT CONDUCTIVITY	C. A. ANGELL, C. LIU, C. SANCHEZ	3/11/93	NATURE, VOL 362
210	SAFT RESEARCH AND DEVELOPMENT CENTER PRESENTATION	GUY CHAGNON	1/31/94	SAFT AMERICA, INC.
211	SANYO LITHIUM BATTERIES	SANYO		SANYO ENERGY (U.S.A.)
212	SDI HIGH TECHNOLOGY UPDATE		1/1/92	SDIO, VOL. 2 NO. 1
213	SECTION V ANNEX G EAGLE-PICHER INDUSTRIAL MODERNIZATION PHASE I RAP REVIEW	ANDREW D. ROCHE	3/19/92	DLA
214	SECTION V, ANNEX J, LISTING OF CONTRACTS/MAJOR PROGRAMS	ANDREW D. ROCHE		DLA
215	SEMI-ANNUAL COMPILATION OF BRIEFS		3/1/93	HORIZON DATA CORPORATION

ID #	Document Title	Author	Document Date	Source of Document
216	SHARP - LISTING OF MILITARY AND FEDERAL BATTERY SPECIFICATIONS	NSWC - CRANE DIVISION		
217	SILVER ZINC BATTERIES	VIC HAILEY		EAGLE PICHER
218	SINTERED-PLATE, NICKEL-CADMIUM BATTERIES INSTRUCTION MANUAL	MARATHON	8/1/92	MARATHON POWER TECHNOLOGIES BATTERY PRODUCTS
219	SOLID-STATE BATTERY	MCGRAW-HILL ENCYCLOPEDIA OF SCIENCE & TECHNOLOGY		VOLUME 10, 6TH EDITION
220	STANDARD HARDWARE ACQUISITION AND RELIABILITY PROGRAM - LIST	WILLIAM JOHNSON		NAVAL SURFACE WARFARE CENTER - CRANE DIVISION
221	STORAGE BATTERY	MCGRAW-HILL ENCYCLOPEDIA OF SCIENCE & TECHNOLOGY		VOLUME 10, 6TH EDITION
222	SULFUR-ALUMINUM SUPERCHARGES A NEW BATTERY	R. LIPKIN	9/4/93	SCIENCE NEWS, VOL. 144, NO. 10
223	SUPER NICKEL-CADMIUM BATTERY DESIGN AND LIFE TEST DATA	R. S. BOGNER	12/11/91	HUGHES AIRCRAFT COMPANY INDUSTRIAL ELECTRONICS GROUP
224	SUPPLY POLICY MANUAL		1/4/92	THE CANADIAN CONTENT POLICY
225	TECHNICAL IMPROVEMENTS FOR LEAD-ACID BATTERIES TO MEET REALISTIC PERFORMANCE GOALS	JEFFREY W. PAVLAT AND ROBERT W. DILLER		ENGINEERING AND COPUTER SCIENCE/UNIVERSITY OF MICHIGAN
226	TECHNICAL MANUAL FOR BATTERIES, NAVY LITHIUM SAFETY PROGRAM RESPONSIBILITIES AND PROCEDURES	COMMANDER, NAVAL SEA SYSTEMS COMMAND	7/20/88	U.S. NAVY SEA SYSTEMS COMMAND
227	THE 1990 NASA AEROSPACE BATTERY WORKSHOP	U.S. SPACE & ROCKET CENTER	12/4-12/6/90	NASA
228	THE 1991 NASA AEROSPACE BATTERY WORKSHOP	U.S. SPACE & ROCKET CENTER	10/29-10/30/91	NASA
229	THE 1992 NASA AEROSPACE BATTERY WORKSHOP	JEFFREY C. BREWER	11/15 - 11/19/92	NASA
230	THE 1992 NASA AEROSPACE BATTERY WORKSHOP	U.S. SPACE & ROCKET CENTER	11/15-11/19/92	NASA
231	THE 1993 NASA AEROSPACE BATTERY WORKSHOP	JEFFREY C. BREWER	11/16 - 11/18/93	NASA
232	THE BATTERY MAN	AN INTERNATIONAL PUBLICATION	7/1/93	
233	THE BATTERY MAN	IBMA - INTERNATIONAL BATTERY MANUFACTURERS ASSOCIATION	7/1/93	
234	THE BATTERY MAN		11/1/93	THE BATTERY MAN
235	THE BATTERY PACK	TDI BATTERIES		TDI BATTERIES
236	THE BUSINESS OF FINDING THE BEST BATTERY	RICHARD A. QUINNELL	12/5/91	EDN

ID #	Document Title	Author	Document Date	Source of Document
237	THE CANADIAN FUEL CELL R&D PROGRAM	M. HAMMERLI AND N. R. BECK		CANMET
238	THE COMMERCIALIZATION OF SOLID POLYMER FUEL CELLS	D. S. WATKINS, R. B. FLEMING, K. W. DIRCKS, K. B. PRATER		BALLARD POWER SYSTEMS INC.
239	THE DOE EXPLATORY TECHNOLOGY RESEARCH PROGRAM	FRANK R. MCLARNON	6/29/94	UNIVERSITY OF CALIFORNIA
240	THE GREAT BATTERY BARRIER	RIEZENMAN	11/1/92	IEEE SPECTRUM
241	THE GREENING OF ELECTRONICS	RUSSELL JOHNSEN		NATIONAL SEMICONDUCTOR
242	THE NASA AEROSPACE BATTERY SAFETY HANDBOOK	GERALD HALPERT, SURAMPUDI SUBBARAO, JOHN J. ROWLETTE	Jul-15-1986	JET PROPULSION LABORATORY
243	THE PREMIER MR. JOHN BANNON, HAS OPENED A NEW $10 MILLION HIGH TECHNOLOGY SUBMARINE BATTERY FACTORY AT PORT ADELAIDE	ASIA-PACIFIC DEFENCE REPORTER	7/1/91	
244	THE STORAGE BATTERY MARKET: PROFILES AND TRADE OPPORTUNITIES	DAVID STONFER	4/1/85	US DEPARTMENT OF COMMERCE
245	THE UPDATE		12/1/94	BALLISTIC MISSILE DEFENSE ORGANIZATION
246	THERMAL BATTERIES			MARTIN MARIETTA
247	THERMAL BATTERIES AND ELECTROEXPLOSIVE DEVICES	RICK PARMLEY		EAGLE PICHER
248	THERMAL BATTERY FOR AIRCRAFT EMERGENCY	STEPHEN KAUFFMAN, GUY CHAGNON		SAFT AMERICA, INC.
249	THERMAL BATTERY INDUSTRY CONCERNS		10/19/93	NAVAL SURFACE WARFARE CENTER CRANE DIVISION
250	THERMODYNAMICS OF NICKEL-CADMIUM AND NICKEL- HYDROGEN BATTERIES	DIGBY D. MACDONALD AND MARK L. CHALLINGWORTH	3/1/93	J. ELECTROCHEM. SOC., VOL 140, NO. 3
251	THIN FILM SOLID-STATE LITHIUM BATTERIES PREPARED BY CONSECUTIVE VAPOR-PHASE PROCESSES	YOSHINORI KANAMORI		JAPAN STORAGE BATTERY COMPANY
252	THIRD PARTIES LOCKED OUT OF NEW TECHNOLOGY	ANDREW GORE AND JAMES STATEN	6/27/94	MACWEEK
253	TRIP REPORT REVIEW OF THERMAL BATTERY MANUFACTURES LOCATE D IN EUROPE		11/18/93	NAVAL SURFACE WARFARE CENTER CRANE DIVISION

ID #	Document Title	Author	Document Date	Source of Document
254	UK DEVELOPS ADVANCED SEDCONDARY BATTERY	INTERNATIONAL DEFENSE REVEIW	9/1/91	
255	ULTRA LOW MAINTENANCE NICKEL CADMIUM BATTERY	SAFT AMERICA INC.		
256	UNITED STATES ADVANCED BATTERY CONSORTIUM	MATTHEW A. DZIECIUCH, FRANK E. JAMERSON, DAIVD R. SMITH		FORD MOTOR COMPANY/GENERAL MOTORS ELECTRIC VEHICLES/CHRYSLER CORPORATION
257	US BATTERY PATENTS	JEC PRESS INC. AND IBA INC.	12/1/93	JEC PRESS INC.
258	US ARMY MISSILE COMMAND REPORT INFORMATION ON THERMAL BATTERIES	MICOM	5/16/94	DEBORAH CAMPBELL
259	UTILITY BATTERY SYSTEMS DEVELOPMENT PROGRAM	A. AKHIL		SANDIA NATIONAL LABORATORIES
260	WHAT WOULD STANDARDIZATION MEAN?	RALPH J. BRODD	10/5/93	VALENCE TECHNOLOGY, INC.
261	WIRELESS MESSAGING MARKET AND OPPORTUNITIES		5/11/92	BIS STRAGIC DECISIONS
262	WORKING LIST # 66140	JOHN NORMANDIN	4/24/93	CANADA DND
263	ZIRCONIUM POWDER CHARACTERIZATION AND PROCESS IMPROVEMENT FOR THERMAL BATTERIES	R. F. GEISENDORFER, K. S. MAZDIYASNI	9/1/75-12/1/76	WRIGHT-PATTERSON AFB

Appendix B - Battery Site Visit Selection Criteria Matrix

SUPPLIER						BATTERY TYPES													SUPPLIER DATA				MILITARY				
Primary / Secondary Ranking						COMMERCIAL						MILITARY							BUSINESS		SS	R & D	CUSTOMER				
BDM RANK	Company	State	Total Customers	Air Force Rank	Army Rank	Lithium	Nickel Metal Hydride	Alkaline	Nickel Cadmium	Lead Acid	Lithium Manganese Dioxide	Mercury	Thermal	Lithium Sulfur Dioxide	Lithium Ion	Lithium Thionyl Chloride	Silver Zinc	Magnesium	% Military	% Commercial	Sole Source	Ongoing R & D Efforts	Navy	Air Force	Army	Marines	Canadian DND
1	Saft America Inc.	NC	5	1	1	●			●					●		●							●	●	●	●	●
2	Ballard Power & Research Inc.	BC	3	2	3	●								●								●			●		●
3	Alexander Mfg.	IA	3	3	8				●			●				●			10	90			●		●	●	
4	Eagle-Picher	MO	4	7	6	●	●		●				●			●							●	●	●		●
5	Gates Energy Products	FL	3	5	7				●	●														●	●	●	
6	Duracell Inc.	CT	3	4		●	●	●			●													●	●	●	●
7	Rayovac	WI	2	9	5			●									●	●				●			●	●	●
8	C & D Charter Power Systems Inc.	PA	2	6						●									6	94			●	●			
9	Concorde Battery Corp.	CA	3							●													●			●	●
10	Marathon Manufacturing Co.	TX	2	8					●															●			●
11	Exide Corp.	PA	2		9				●	●									97	3			●			●	
12	Exide Electronics	KY	3																				●	●		●	

Appendix B - Battery Site Visit Selection Criteria Matrix

SUPPLIER						BATTERY TYPES													SUPPLIER DATA				MILITARY				
Primary / Secondary Ranking						COMMERCIAL							MILITARY						BUSINESS		SS	R & D	CUSTOMER				
BDM RANK	Company	State	Total Customers	Air Force Rank	Army Rank	Lithium ...	Nickel Metal Hydride	Alkaline	Nickel Cadmium	Lead Acid	Lithium Manganese Dioxide	Mercury	Thermal	Lithium Sulfur Dioxide	Lithium Ion	Lithium Thionyl Chloride	Silver Zinc	Magnesium	% Military	% Commercial	Sole Source	Ongoing R & D Efforts	Navy	Air Force	Army	Marines	Canadian DND
13	Eveready	MO	2			●		●	●								●							●		●	
14	Johnson Controls	WI	2						●	●														●		●	
15	ACR Electronics Inc.	FL	2															●					●			●	
16	Battery Engineering Inc.	MA	2			●										●							●	●			
17	Tadiran Electronic Industries Inc.	NY	2			●			●							●							●			●	
18	W. R. Grace	MD	2			●																		●		●	
19	Delco/Remy - Div. of GM	IN	2			●				●														●		●	
20	BST Systems Inc.	CT	1														●		90	10			●				
21	Yardney Electric Corp.	CT	1					●	●				●				●							●			
22	Power Conversion Inc.	NJ	1		2	●					●			●											●		
23	Progressive Technologies Inc.	NC	1					●								●							●				
24	Eveready (Canada)	ONT	1					●								●											●

Appendix B - Battery Site Visit Selection Criteria Matrix

SUPPLIER						BATTERY TYPES													SUPPLIER DATA				MILITARY				
Primary / Secondary Ranking						COMMERCIAL							MILITARY						Percent		Sole	R & D	CUSTOMER				
BDM RANK	Company	State	Total Customers	Air Force Rank	Army Rank	Lithium ...	Nickel Metal Hydride	Alkaline	Nickel Cadmium	Lead Acid	Lithium Manganese Dioxide	Mercury	Thermal	Lithium Sulfur Dioxide	Lithium Ion	Lithium Thionyl Chloride	Silver Zinc	Magnesium	% Military	% Commercial	Sole Source	Ongoing R & D Efforts	Navy	Air Force	Army	Marines	Canadian DND
25	Electrofuel Mfg. Co. Ltd.	ONT	1			●																●					●
26	Saft	GA	1		4				●																●		
27	Alupower Canada Limited	ONT	1																			●					●
28	GNB Industrial Battery Co.	IL	1							●									25	70			●				
29	Hydro-Quebec	QUE	1																			●					●

Appendix C - Battery Sector Study Sites Contacted

	BATTERY SECTOR STUDY SITES CONTACTED			
	Company / Lab	City	State	Point of Contact
1	ACR Electronics Inc.	Ft. Lauderdale	FL	Paul Frank
2	Alexander Mfg. Co.	Mason City	IA	Tony Andolino
3	Alupower Canada Limited	Kingston	ONT	Dr. John Stannard
4	Army Research Labs @ Ft. Monmouth	Ft. Monmouth	NJ	Dr. Bob Hamlen
5	Ballard Power & Research Inc.	Vancouver	BC	Dr. Allen Harkness
6	Battery Engineering Inc.	Hyde Park	MA	Bob Fay
7	BST Systems, Inc.	Plainfield	CT	Joseph F. Houlihan
8	C & D Charter Power Systems Inc.	Plymouth Meeting	PA	Leo Dehlinger
9	Concorde Battery Corp.	West Covina	CA	Skip Koss
10	Delco/Remy - Div. of GM	Indianapolis	IN	Karen Collins
11	Eagle Picher	Colorado Springs	CO	Rolan Farmer
12	Eagle-Picher	Joplin	MO	Information obtained from MICOM's thermal battery study
13	Electrofuel Mfg. Co. Ltd.	Toronto	ONT	Dr. Sankar Das Gupta
14	GNB Battery	Lombard	IL	George Hunt
15	Hydro-Quebec	Montreal	QUE	Dr. Guy Belanger
16	Johnson Controls	Milwaukee	WI	Jim Winnistorfer
17	Marathon Manufacturing Co.	Waco	TX	Pete Spink
18	Naval Surface Warfare Center	Crane	IN	Jim Gucinski
19	Naval Surface Warfare Center	White Oak	MD	Jim Barnes
20	Power Conversion Inc.	Saddlebrook	NJ	Dr. Jim Sullivan
21	Saft America Inc.	Cockeysville	MD	Guy Chagnon
22	Saft America Inc.	Valdese	NC	Ric Raines
23	Saft America Inc.	Valdosta	GA	Del Nary
24	Whittaker Power Storage Systems	Denver	CO	Vern Bjork
25	Wright Labs @ WPAFB	Dayton	OH	Dick Marsh
26	Yardney	Pawcatuck	CT	Peter Karpinski

Appendix D - Manufacturing Site Visit Questionnaire

Battery Sector Study Manufacturers Questionnaire

GENERAL INFORMATION

Name of Company:

Address:

Telephone and Fax numbers:

POC:

COMPANY INFORMATION

Company size:

Are you a subsidiary of another company, privately or publicly held:

Sales Volume in dollars and quantity to military and commercial (by battery type):

Percentage of overall sales (dollars) to military and commercial (by battery type):

BATTERY TYPE(S) PRODUCED

Battery Type(s) Produced (battery chemistry):

Are any of the battery types you produce used by the military as well as commercial customers:

For each battery type how long have you been manufacturing it:

What systems (if known) are the batteries used in:

For each battery type, name competing vendor(s):

Has your company developed any new battery type technology:

MANUFACTURING

What is your production capacity: By shift / by day / by battery type (cells):

What raw materials/components do you use?

Where do you obtain your raw materials (company, country):

Do you have the capability to produce custom battery type configurations:

In what format are instructions/specifications for manufacture received from the government (TDPs, Mil-Specs):

Have you made any capital investments (of your own) to support military battery production:

If so how much: When: What for:

Does your company possess any unique manufacturing capabilities:

If so what kind: Acquired or developed in house: Developed by whom:

Has your company developed any new technologies related to battery manufacturing:

Briefly, what is your maximum capacity:

What will it take to get to maximum capacity:

What impediments will you encounter in doing such a capacity surge:

How much time would you need to get to maximum capacity:

CUSTOMERS

Main customer(s):

Battery types each individual customer buys:

If your marketplace extends beyond domestic borders what markets do you advertise and/or sell in:

If so what battery type(s):

TESTING & EVALUATION

Do you have any test/evaluate capabilities in house:

What tests are performed outside your facility:

GOVERNMENT FUNDING

Are you involved in any type of DoD/DND funding and/or programs (R&D, ManTech, Title III, Technology Transfer, Advanced Research Projects Agency Technology Reinvestment Program, Defense Development Sharing Arrangement, etc.):

Are you aware that such programs exist:

RESEARCH and DEVELOPMENT

Do you have any type of R&D at your facility:

Are you involved in any R&D with academia or another company:

If so where, with whom, what type of technology (battery):

IMPEDIMENTS

What are the shortfalls/weaknesses in selling to/dealing with the US/Canadian government:

Are there any policy/regulatory issues, environmental regulations, or state/local/federal laws which affect your business:

Have you ever geared up production to support a military emergency: If so when:

JOINT EFFORTS

Are you involved in any joint/collaborative efforts with another company, US government, Canadian Government:

Do you have any licensing agreements with other companies:

Would you be interested in such endeavors:

FUTURE

What demand do you foresee (military/commercial) for the battery types you produce:

What is the impact of significant reduction in military demand to your company:

How are changes in battery technology affecting your company:

Give a general assessment of your company's future ability to assist the military in meeting its future battery requirements (relevant to your company's products) through the 1990's and into the 21st century:

What do you forecast as the changes in your production capacity over the next three to five years?

Battery Sector Study R&D / Laboratory Facility Questionnaire

GENERAL INFORMATION

Name of Company:

Address:

Telephone and Fax numbers:

POC:

FACILITY INFORMATION

Facility size:

Are you an independent test/evaluation facility or are you affiliated with another company or a government agency, are you privately or publicly held:

How many scientists, technicians etc. do you employ:

Percentage of overall testing done for military / commercial (by battery type):

How long have you been in operation:

How do you obtain work to test - Do you have long standing contracts with any companies, do you advertise - if so where:

BATTERY TYPE(S) TESTED

Battery Type(s) Tested:

Are any of the battery types you test/evaluate sold in military and commercial markets:

For each battery type how long have you been testing/evaluating it:

What systems (if known) are the batteries used in:

Are you in competition with other test/evaluate facilities: If so whom:

TESTING

Where do you obtain your criteria to test/evaluate against:

What types of testing/evaluating do you do:

- Qualification
- Conformance to spec
- Environmental
- Production
- Safety
- Disposal

Do you possess any specialized equipment and/or capabilities:

Appendix E - R&D / Laboratory Facility Questionnaire

Are you certified to grant accreditations according to regulations/policies (government, accepted standards)

Has your company developed any new testing/evaluating technology:

CUSTOMERS

Main customer(s):

If your marketplace extends beyond domestic borders what markets do you advertise and/or sell in:

GOVERNMENT FUNDING

If you are not affiliated with a government agency are you involved in any type of government funding and/or programs (ManTech, Title III, Technology Transfer, etc.):

Are you aware that such programs exist:

RESEARCH and DEVELOPMENT

Do you have any type of R&D at your facility:

Are you involved in any R&D with academia or another company:

If so where, with whom,:

IMPEDIMENTS

What are the shortfalls/weaknesses in dealing with the US government:

Are there any policy/regulatory issues, environmental regulations, or state/local/federal laws which affect your business:

JOINT EFFORTS

Are you involved in any joint/collaborative efforts with another company, US government, Canadian Government:

Would you be interested in such endeavors:

FUTURE

What is the impact of significant reduction in military demand to your company:

How are changes in battery technology affecting your company:

Give a general assessment of your company's future ability to assist the military in meeting its future battery requirements (relevant to your company's products) through the 1990's and into the 21st century: